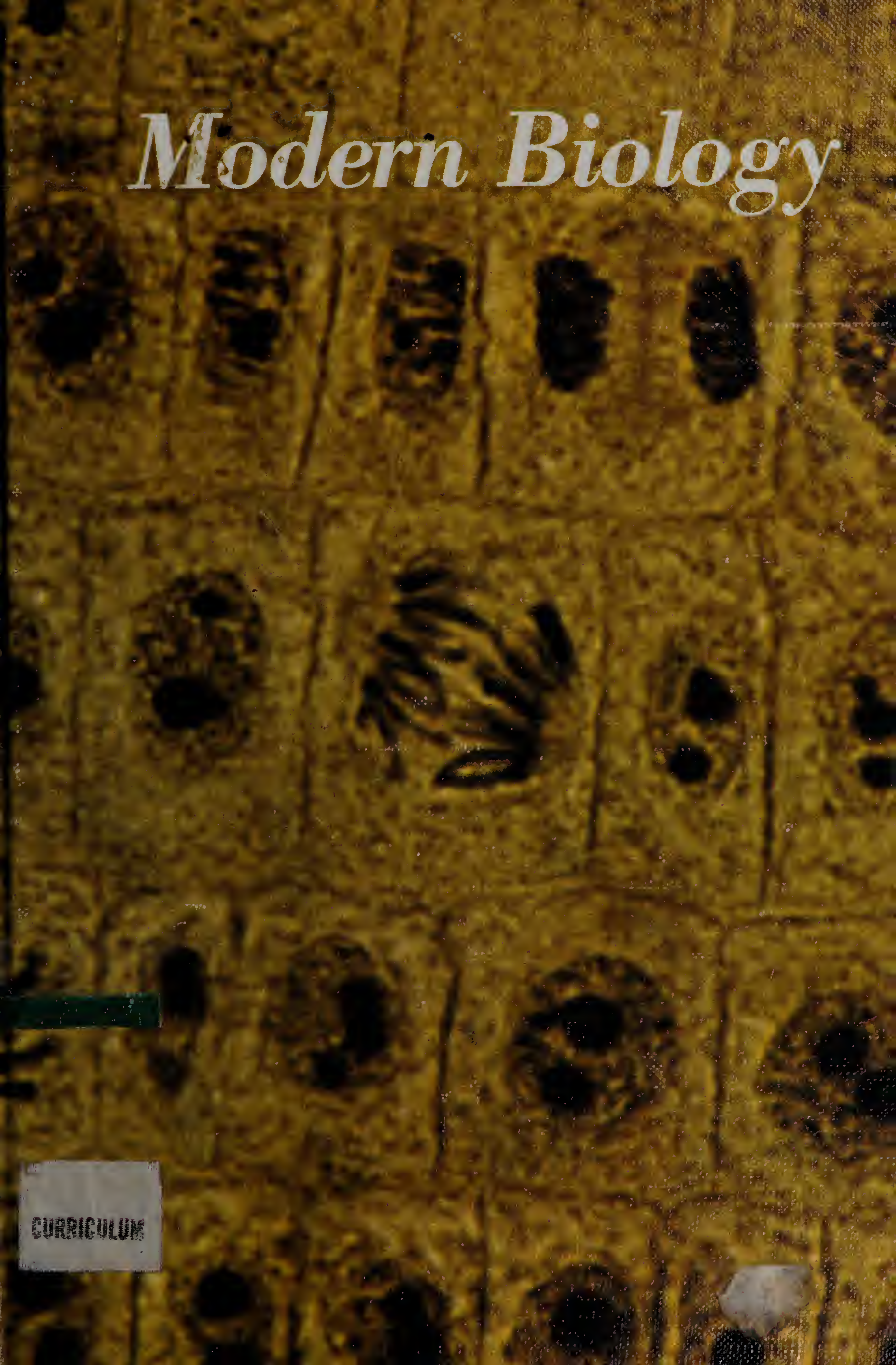


Modern Biology

CURRICULUM

THIS BOOK IS THE PROPERTY OF:

STATE ____________________
COUNTY ____________________
PARISH ____________________
SCHOOL DISTRICT ____________________
OTHER ____________________

Book No. __________
Enter information in spaces to the left as instructed

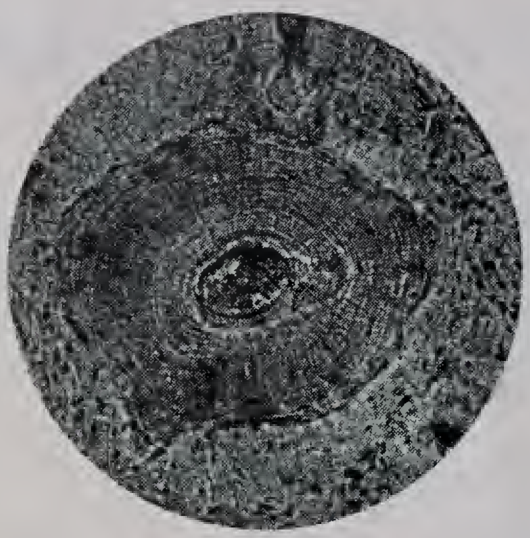
ISSUED TO	Year Used	CONDITION	
		ISSUED	RETURNED

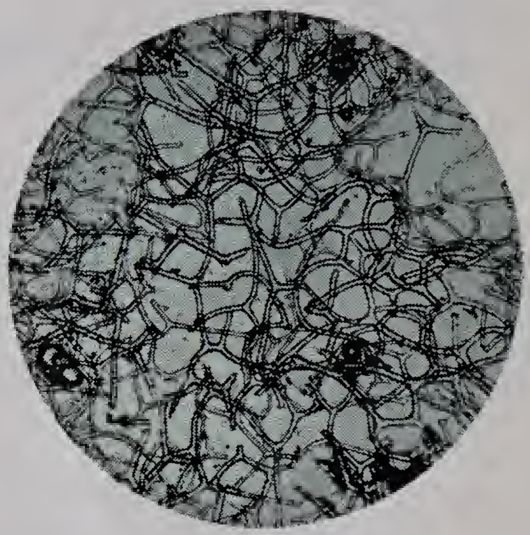
PUPILS to whom this textbook is issued must not write on any page or mark any part of it in any way, consumable textbooks excepted.

1. Teachers should see that the pupil's name is clearly written in ink in the spaces above in every book issued.
2. The following terms should be used in recording the condition of the book: New; Good; Fair; Poor; Bad.

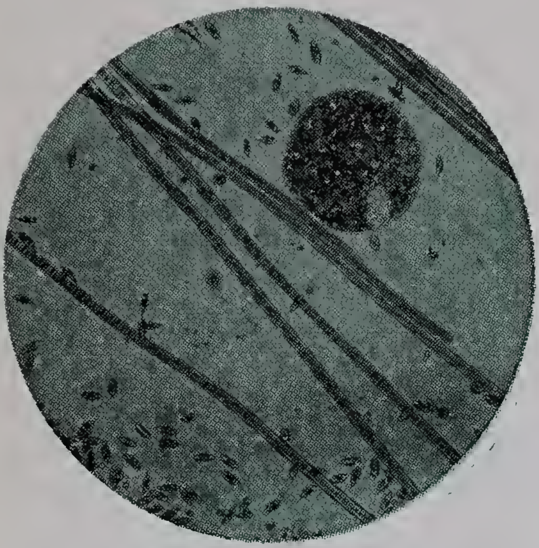
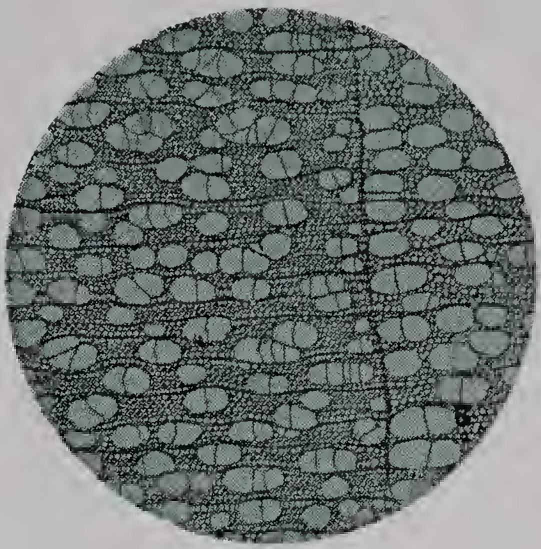
Ex libris
universitatis
albertaensis

QUAECUMQUE VERA





JAMES H. OTTO • ALBERT TOWLE

MODERN BIOLOGY

HOLT, RINEHART AND WINSTON, INC., NEW YORK

ABOUT THE AUTHORS

JAMES H. OTTO is head of the Science Department
at George Washington High School, Indianapolis, Indiana
ALBERT TOWLE is head of the Science Department
at James Lick High School, San Jose, California

Cover photograph: Mitosis in onion root tip (Walter Dawn)
Unit and chapter opening photographs: 1. Model of DNA molecule (Walter Dawn); 2. *Drosophila* chromosomes (Walter Dawn); 3. Protozoans (Walter Dawn); 4. Sections of woody stem (USDA); 5. Spongin fibers (Walter Dawn); 6. Cross section of bone (Walter Dawn); 7. Human blood with *Trypanosoma gambiensi* (Walter Dawn); 8. Drop of pond water (Bausch and Lomb, Inc., Rochester, N.Y.)

12345 039 1817161514

COPYRIGHT © 1965 BY HOLT, RINEHART AND WINSTON, INC.

Previous Editions Copyright 1947, 1951, © 1956, 1960, 1963
by Holt, Rinehart and Winston, Inc.

All Rights Reserved

Printed in the United States of America

03-047900-2

LIBRARY
UNIVERSITY OF ALBERTA

PREFACE

Biology today is vastly different from biology ten years ago. In the field of cellular biology, the electron microscope has yielded discoveries long suspected but incapable of positive proof. Improved techniques in biochemistry have revealed new vistas at the molecular level. Man's understanding of genetics, microbiology, and ecology has reached new heights. As a result of this increased body of knowledge, it is possible to encompass only the basic principles during one school year of study.

The authors of MODERN BIOLOGY have always felt that the learning process should involve a mastery of certain fundamental biological concepts at the beginning of the program. From these initial understandings, the student should then progress from the cell to protists, to plants and animals, and to man. Culminating his biological knowledge, the interrelationships of living things and their environmental adaptations should bring about a clearer comprehension of the significance of life and its importance in human welfare. Accordingly, this revision of MODERN BIOLOGY contains the most recently available knowledge, but the authors have avoided selecting any one or two of these areas as deserving of primary emphasis at the expense of other equally important areas.

The authors have preserved the approach and methodology that has evolved through the years so successfully in secondary school classrooms. These features have been tested, tried, and proved effective by thousands of teachers in our nation's schools. Many professional biologists who are making significant discoveries today in the research laboratories and who learned from earlier editions of this text are evidence of the motivational value of such a course.

In this complete revision some material from previous editions has been telescoped to produce a pattern more consistent with current trends in the various science curricula. Thus, conservation is somewhat reduced in scope as is the subject of disease. Both these topics are generally covered in the elementary and junior high school science programs and do not now require emphasis they enjoyed in previous editions of this book.

The book begins with molecular and cellular biology from which it logically moves into reproduction and genetics. From there it moves to evolution and hence into classification, thus building a basic structure of biological principles on which to build further concepts and facts — as much as circumstances, interest, and

2391411

curricula requirements permit. This orderly arrangement has advantages that no other program today possesses — flexibility. The program is adapted to either a concentrated course in certain areas of biology or a survey course which hits the high spots.

The greatly expanded, thoroughly modern unit on genetics is a feature of this revision. Also modern in scope is the unit on molecular and cellular biology, which includes now the treatment of cell reproduction formerly discussed much later in the text. The ecology unit is completely new and a more intensive discussion of the subject is presented, together with the treatment of conservation, since the two go hand in hand and one can hardly be mentioned at the secondary school level without the other.

The language of science has again been an important consideration, as in previous editions of this book, and the style of writing has been kept as informal as possible. The average ninth and tenth grade student is seldom a reader who can digest material much beyond his grade level. Therefore, the authors have tried to keep the readability commensurate with the age of the student. Difficult words are pronounced phonetically and all new words or terms are printed in boldface italics and are defined the first time they appear.

The present authors are deeply indebted to the late Truman J. Moon, whose successful texts *Biology for Beginners* and *Biology* were the predecessors of this book. Mrs. Elizabeth H. Crider, teacher of biology in George Washington High School, Indianapolis, Indiana has helped the senior author in the preparation of the manuscript for Units Two and Six and he herewith gratefully acknowledges her assistance. Mrs. Mildred I. Ross, Science Librarian at the George Washington High School in Indianapolis, has again prepared the bibliographies at the ends of each unit, and in this revision periodicals as well as books are included. The photographs for this revision were obtained by Frances L. Orkin.

Each unit has been read not only by a high school teacher who has had long classroom experience, but also by a specialist in that particular field of biology at the university level. These biologists have given generously of their time and have offered invaluable suggestions and criticisms. The authors express their deep appreciation and are grateful to each person for his active interest in the project.

The university professors are as follows: Dr. Donald R. Griffin of Harvard University; Dr. Donald Heyneman of the University of California; Dr. David J. Merrell of the University of Minnesota; Dr. Peter M. Ray of the University of Michigan; Dr. Philip Siekevitz of the Rockefeller Institute; Dr. William R. Sistrom of the University of Oregon; Dr. Richard C. Wolf of the University of Wisconsin.

The high school teachers are: Lyle D. Anderson of West High School, Waterloo, Iowa; William Berman of Tilden High School, Brooklyn, New York; Richard K. Hayes of Pilgrim High School, Warwick, Rhode Island; James F. Snyder, Walt Whitman High School, Huntington Station, New York.

CONTENTS

UNIT ONE THE NATURE OF LIFE 1

Chapter 1: The Science of Life 2
Chapter 2: The Living Condition 18
Chapter 3: The Chemical Basis of Life 33
Chapter 4: The Structural Basis of Life 55
Chapter 5: The Cell and Its Environment 70
Chapter 6: Cell Nutrition 81
Chapter 7: Cell Metabolism 94
Chapter 8: Cell Growth and Reproduction 103

UNIT TWO THE CONTINUITY OF LIFE 115

Chapter 9: Principles of Heredity 116
Chapter 10: The Genetic Material 131
Chapter 11: Genes in Human Populations 155
Chapter 12: Applied Genetics 170
Chapter 13: Organic Variation 182
Chapter 14: The Diversity of Life 199

UNIT THREE MICROBIOLOGY 211

Chapter 15: The Viruses 212
Chapter 16: Bacteria and Related Organisms 222
Chapter 17: Infectious Disease 238
Chapter 18: The Protozoans 254
Chapter 19: The Fungi 265
Chapter 20: The Algae 277

UNIT FOUR MULTICELLULAR PLANTS 293

Chapter 21: Mosses and Ferns 294
Chapter 22: The Seed Plants 303
Chapter 23: Root Structure and Function 313
Chapter 24: Stem Structure and Function 325

Chapter 25: Leaf Structure and Function 341
Chapter 26: Reproduction in Flowering Plants 352

UNIT FIVE BIOLOGY OF THE INVERTEBRATES 373

Chapter 27: Sponges and Coelenterates 374
Chapter 28: The Worms 385
Chapter 29: Mollusks and Echinoderms 399
Chapter 30: The Arthropods 410
Chapter 31: Insects — A Representative Study 423
Chapter 32: Insect Diversity 432

UNIT SIX BIOLOGY OF THE VERTEBRATES 451

Chapter 33: Introduction to the Vertebrates 452
Chapter 34: The Fishes 459
Chapter 35: The Amphibians 472
Chapter 36: The Reptiles 489
Chapter 37: The Birds 506
Chapter 38: The Mammals 522

UNIT SEVEN THE BIOLOGY OF MAN 541

Chapter 39: The History of Man 542
Chapter 40: The Body Framework 551
Chapter 41: Nutrition 565
Chapter 42: Transport and Excretion 581
Chapter 43: Respiration and Energy Exchange 600
Chapter 44: Body Controls 612
Chapter 45: Alcohol, Narcotics, and Tobacco 630
Chapter 46: Body Regulators 639
Chapter 47: Reproduction and Development 648

UNIT EIGHT ECOLOGICAL RELATIONSHIPS 659

Chapter 48: Introduction to Ecology 660
Chapter 49: The Habitat 672
Chapter 50: Periodic Changes in the Environment 685
Chapter 51: Biogeography 699
Chapter 52: Soil and Water Conservation 712
Chapter 53: Forest and Wildlife Conservation 723

Appendix 743
Glossary 755
Index 774

UNIT ONE

THE NATURE OF LIFE

What is life? What is the elusive condition we refer to as the living state? All living things have chemical similarities. They have structural characteristics which set them apart from nonliving materials. They grow by organizing more of their own substance. They reproduce and perpetuate life, age after age. They constantly require energy to maintain their many chemical activities. In your study of biology you will start with an unknown — the living state — and will explore it in many ways. You may never explain life, but your investigations will bring you to a closer understanding of the marvelous living condition.

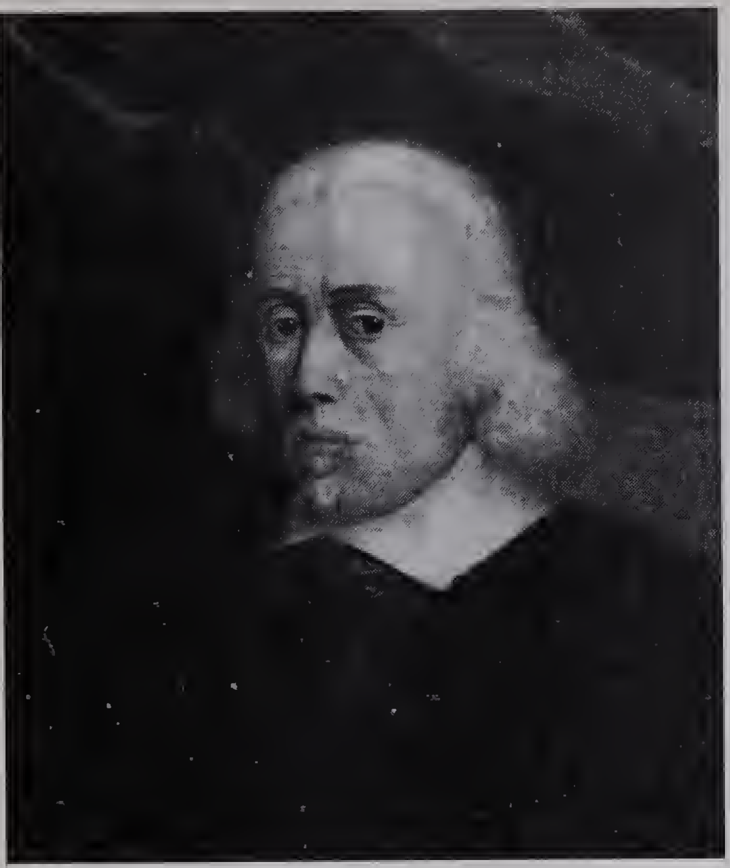
CHAPTER 1

THE SCIENCE OF LIFE

Biology in a golden age. What is biology? The word comes from the Greek *bios*, which means "life," and *logos*, which means "study of," or "science of." Biology is the knowledge about living things that has come to us from previous generations and to which we are adding the contributions of biologists of our time. Like all the other sciences, biology is a method of investigating events and problems we need to solve. It arises from curiosity about life and our need to survive and to improve our position in the living world.

Biology, like the other sciences, is pushing forward at an unbelievable rate. It is probably safe to say that we have gained more biological knowledge in the past 20 years than in the previous 20 centuries! This is truly a golden age in biology. Why this sudden explosion of knowledge in our time? Let us examine the position of biology today and see if we can discover what lies behind the many achievements of recent years.

Science is not limited by national boundaries. With the coming of the Renaissance, science began to develop on a worldwide basis. Slowly at first, but with increasing pace, scientists pushed back the frontier of ignorance, superstition, and prejudiced thinking that had stifled progress in medieval times. A Belgian medical student, Andreas Vesalius, rebelled against medieval medicine and established the scientific study of anatomy in the 16th century. In the 17th century, William Harvey, an English physician, disputed the ancient belief that blood ebbed and flowed in the veins of the body like the tides of the sea and proposed that it circulated through arteries and veins. Later in this same century, Marcello Malpighi (*mal*-pee-gee), an Italian scientist, saw vessels in the lung of a frog and proved Harvey's theory of circulation. Malpighi had a microscope; Harvey did not. In the 18th century, Edward Jenner, an English doctor, performed the first vaccination when he immunized a small boy against smallpox. Louis Pasteur of France established the science of bacteriology in the 19th century. A few years later Robert Koch (kohk) of Germany gave the world a method of investigating infectious diseases and techniques for culturing bacteria in the laboratory. A century ago Gregor Mendel (*men*-d'l), an Austrian monk, conducted his famous experiments with garden peas and discovered laws that still serve as the basis for much of the modern science of heredity. A few years later, Paul Ehrlich, a German doctor, discovered an arsenic compound that would kill the syphilis organism in the



1-1 William Harvey is best known for his classic investigation of circulation. He also published work on embryology and physiology. (National Portrait Gallery, London)

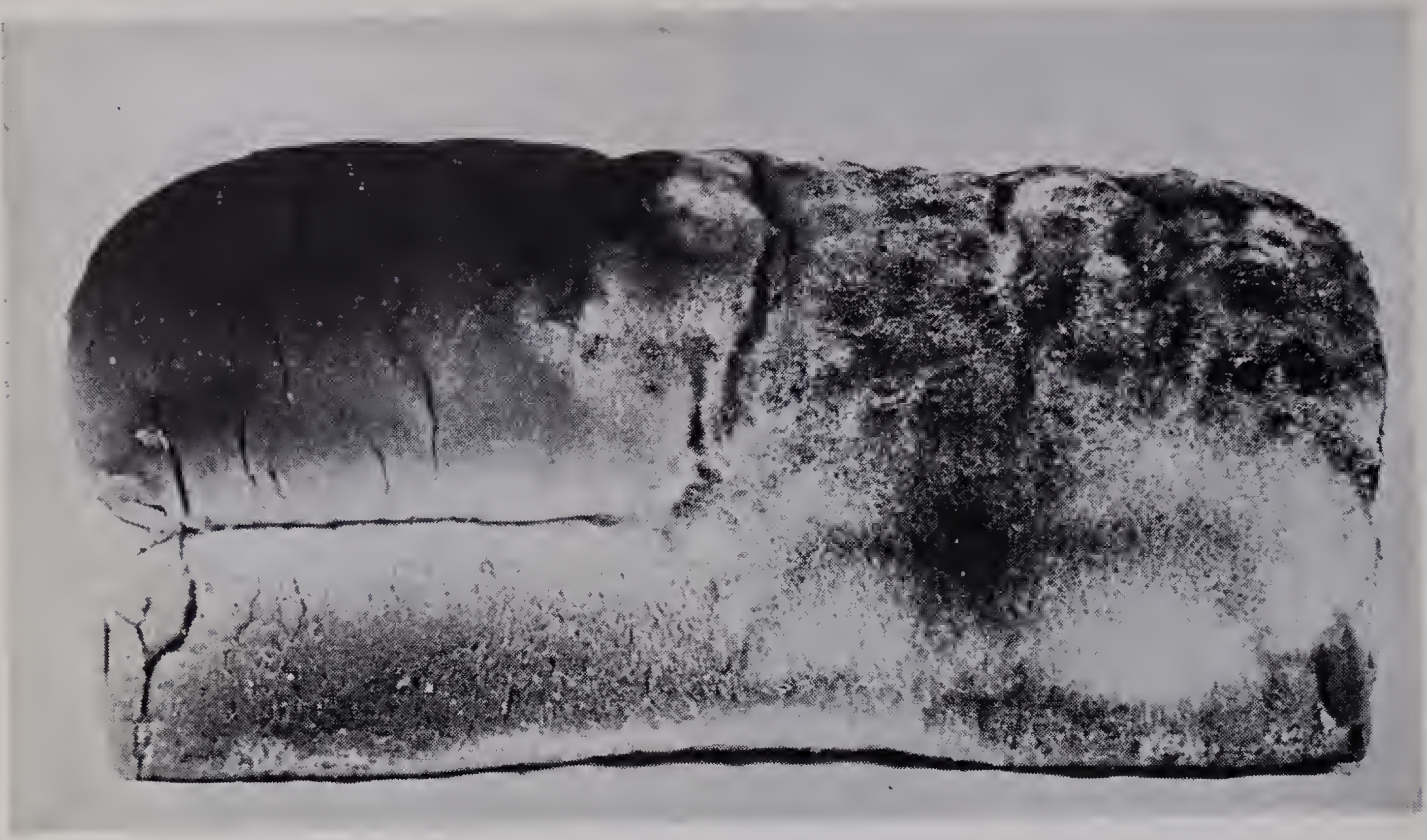
human blood stream. This ushered in the age of chemotherapy in medicine. In 1929 an English biologist, Alexander Fleming, discovered penicillin, the first of a long line of antibiotics.

These are but a few of the important milestones in the progress of biological science through the recent centuries. A contribution of one scientist becomes the property of scientists to follow. In this way scientific knowledge is compounded year after year and decade after decade.

Through the years scientists have established a method of investigation. When science succeeded in throwing off the yoke of superstition and prejudice, a new system of objective thought and investigation developed. You may call it the scientific method. Actually it is nothing more than unrestrained common sense. Man is naturally curious. He has always sought explanations for the events and phenomena he could not understand. In earlier times he was satisfied with unreasonable, unproved answers derived from nothing more than superstition. A person's life was supposedly influenced by the position of heavenly bodies at the time of his birth. Did anyone ever prove this? Did anyone even try? The mud in a pond was supposedly transformed into eels, fish, or frogs. The air from a marsh was thought to cause malaria. The name of this disease means, literally, "bad air."

Several centuries were necessary to gain for the scientist the freedom he requires — freedom to investigate; freedom to prove and disprove; freedom to base his conclusions on observed facts.

Science has progressed at a remarkable rate in areas related to biology. Such related areas include chemistry, physics, earth science, oceanography, and space science. At one time definite lines could be drawn between the major areas of science. Today no such separations exist. All scientific knowledge is interrelated. As you study the organization of the many substances involved in the living condition, you may be surprised to find that life can be finally reduced to a biochemical state. Growth is chemical. Response is chemical. Heredity is chemical. In the last analysis everything about life is chemical because it involves matter and changes in matter. Life also involves energy changes. The forces that govern the changes in the matter of our earth have a vital influence on all of life. How can we separate physics from biology? Satellites sent aloft are sending back information that is changing all our concepts of the shape of the earth. The earth is not round but somewhat pear-shaped. It is flattened at the poles and



1-2 The effect of acetic acid on bread mold. The left half of the loaf was treated with vinegar; the right half was not treated. Is this effect chemical or biological? (Fleischmann Laboratories, Standard Brands, Inc.)

bulges at the equator. Its surface has great raised areas and depressions far more extensive than mountain ranges and valleys. Its crust varies in thickness.

Do all these factors have a profound influence on life and the distribution of living organisms over the face of the earth? Only time will tell. This is a completely new area for investigation. Oceanographers are exploring the ocean depths and plotting great currents that circulate water throughout the expanse of the seas. Just how do these currents influence the distribution of life in the seas? Many generations of biologists will investigate problems such as these. Science is progressing rapidly on all fronts. Advances in all of these fields are bound to have a dynamic influence on our study of life.

Progress in biology is directly related to the tools available for research. Biology took a giant step forward in the 18th and 19th centuries with the invention and perfection of the light microscope such as you have in your high school laboratory. Without magnification, the biologist could examine only the gross structures of an organism — a leaf or stem, a heart or a kidney. But organs such as these are composed of much smaller parts. Without lenses to see cells and tissues, many significant discoveries of the past centuries would have been impossible. Without a microscope Louis Pasteur could never have given his germ theory to the scientists of the world. The whole area of microbiology, vital in biology today, could never have developed.

The modern light microscope reveals much of the structure of a cell. But beyond the limit of visibility with even the finest light microscope are cell structures that have provided clues for the dramatic discoveries of the past few years. This remarkable tool of the modern biologist is, as you undoubtedly know, the electron microscope. We will describe this important biological tool later in this chapter.

As a result of the new techniques in microscopy and the advances in chemistry outlined on page 3, biologists in the last twenty years have concentrated more on the cellular and molecular levels of life. While in the past biologists were more concerned with the great diversity of living things, in recent years they have become more interested in their unity. Cells and certain molecules are common to all organisms. As you study biology it will become obvious to you that certain principles govern everything that is alive — that living things are as remarkable for their similarities as they are for their differences.

The scientist has begun to recognize his own limitations. In medieval times science was considered absolute authority. Scientific "truths" handed down from early times in the body of knowledge were not to be questioned, much less disputed or disproved. Many were those who were ridiculed or persecuted or forced to flee because they dared to disagree with the established authority. Even a generation ago science was considered much more exact than it is today. Fortunately, we no longer consider any scientific explanation a final answer. Any concept must be subject to change and revision in the light of new discoveries.

1-3 The biologist of today is often concerned with the chemical aspects of life. (Parke, Davis & Co.)

The public has come to accept and support modern science. Two hundred years ago, townspeople threw rocks at Edward Jenner when he vaccinated a boy against smallpox and probably saved his life. One hundred years ago, people ridiculed Louis Pasteur when he tried to convince them that invisible microbes could cause infectious disease. Today both of these great scientists of the past would undoubtedly have received Nobel prizes for their outstanding contributions.

A century of research and triumph in our time. The conquest of polio is an excellent example of a gigantic program of biological research extending over a period of more than 100 years. Scientists of many nations made contributions that led step by step to the eventual victory. The story reads like a detective story. Each discovery opened a door for further investigation. The conquest of polio is especially interesting to us because it represents a tremendous undertaking, supported by the American public through 3,000 chapters of The National Foundation for Infantile Paralysis, and the contributions of millions of citizens through the March of Dimes campaign in honor of a President of the United States, Franklin D. Roosevelt, himself a victim of polio.

Polio is short for *poliomyelitis* (*poh*-lee-oh-my-e-*ly*-tis), the medical name of the disease. It is a virus infection of nerve cells in the brain and spinal cord. Depending on the seriousness of the infection, the cells may be damaged or destroyed. In spinal polio, temporary or permanent paralysis of any body part may occur, although the limbs are most frequently involved. In bulbar polio the infection centers in the medulla, a region at the base of the brain sometimes called the spinal bulb. In bulbar polio paralysis of breathing muscles may occur. However, in 60 percent of the cases of polio, there is no permanent damage. Permanent paralysis occurs in only 14 percent of the cases.

Progress in the investigation of polio was slow; one reason was the fact that there were many mistaken ideas about the disease. We might begin with the familiar name, "infantile paralysis," which gives two false impressions. Polio is not primarily a disease of infants — it may strike at any age, and the infection does not always result in paralysis. There was also a mistaken idea that polio was a disease of the bones and muscles rather than of nerve cells in the spinal cord.

Milestones in the conquest of polio. In 1840 the little son of a German villager was stricken with paralytic polio. Both of his legs were limp and useless. His mother brought him to Dr. Jacob Heine (*hy*-ne), a bone specialist in Cannstadt, Germany. Dr. Heine examined his young patient thoroughly and came to an important medical conclusion. Neither the bones nor the muscles of the boy's legs were diseased. The problem centered in the nerves that controlled the leg muscles. This was the first association of polio with the central nervous system. Dr. Heine wrote a book describing his observations, the earliest published study of the disease.

The first known polio epidemic occurred in Stockholm in 1887. During this epidemic Dr. Medin of the University of Stockholm made extensive studies of polio cases and published the first report on the early symptoms of the infection.

Another terrible epidemic of polio struck the Scandinavian countries in 1905. This epidemic attracted worldwide attention and resulted in a detailed study of the spread of the infection by Dr. Wickman, another early investigator. Dr. Wickman advanced the theory that polio was spread by human carriers.

Three years later, in 1908 and 1909, Dr. Karl Landsteiner and Dr. Erwin Popper conducted studies of polio in Vienna. They succeeded in producing polio infections in monkeys and first demonstrated that the infection is caused by a virus that attacks the cells of nerves in the spinal cord.

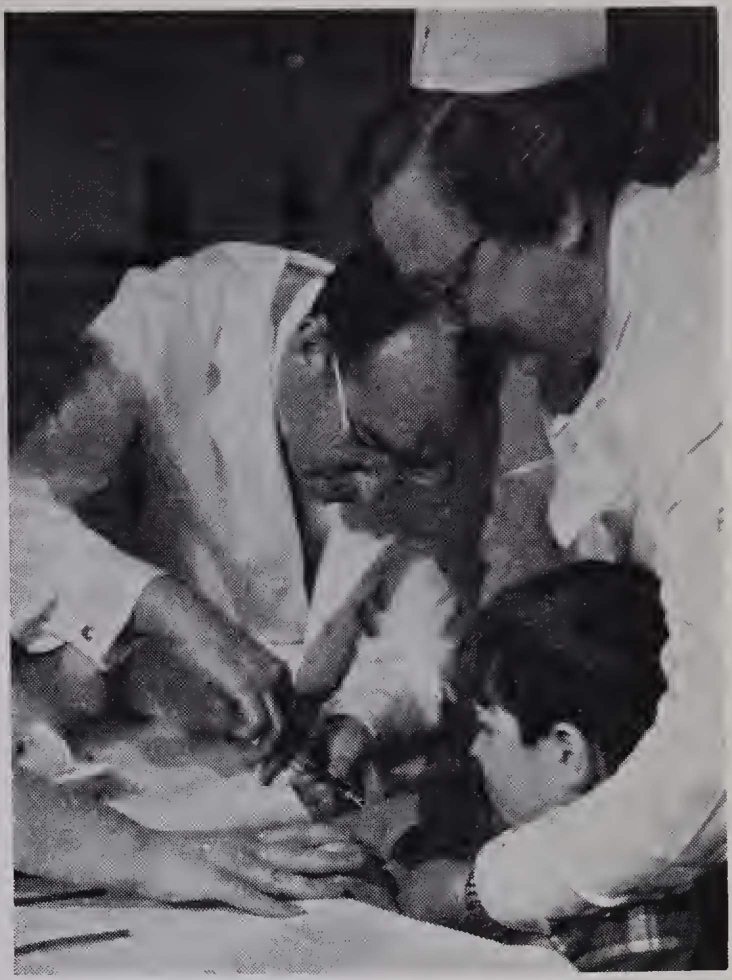
Forty years later, in 1949, another milestone was passed when Dr. John F. Enders of Harvard University and two of his associates, Dr. Thomas H. Weller and Dr. Frederick C. Robbins, succeeded in growing polio virus in tissue cultures in test tubes. They grew the virus in a variety of animal tissues, but found that monkey kidney tissue was most satisfactory. For this significant advance the Nobel prize in medicine and physiology was awarded in 1954.

The discovery of gamma globulin. One of the goals of all who worked with polio was the production of an immune product that could be used to transfer immunity by injection into the blood stream. This major breakthrough in the conquest of polio came in 1951 and 1952. A part of the human blood known as gamma globulin was found to contain antibodies against the polio virus. Blood banks were available by this time to furnish an abundant supply of gamma globulin from adult donors.

A gigantic test was devised to determine the effectiveness of gamma globulin. Injections were given to 55,000 children. By comparing the incidence of polio among these protected children with children who were not immunized, it was definitely established that gamma globulin was effective. However, the battle against polio was not yet won. While gamma globulin establishes immunity immediately, making it valuable in protecting a child during an epidemic or at a time of known exposure, the goal was not yet reached. Injected gamma globulin gives only temporary or passive immunity, lasting no more than eight weeks.

The long-awaited polio vaccine. Our scene now shifts to the University of Pittsburgh and the laboratory of Dr. Jonas E. Salk. Dr. Salk found, as had Enders, that polio virus could be grown most satisfactorily in cultures of monkey kidney tissue. After a short period of rapid growth, the virus was removed and made harmless by treatment with formaldehyde. Before it was used in field tests, the Salk vaccine was checked carefully for effectiveness and safety.

Finally the anxiously awaited tests to determine the effectiveness of the vaccine were conducted under the direction of the National Foundation. In 1954, 1,830,000 school children were used as subjects. Only 440,000 were given the vaccine. The others were given a sterile solution that looked like the vaccine but had no medical value. All children and their injections were coded. Neither the children nor the doctors who gave the injections knew which children received vaccine and which ones served as controls.



1-4 Dr. Jonas Salk shown injecting one of the 440,000 school children with the trial vaccine that had been developed after many years of research. Another large group of children, acting as controls, were given sterile solution. (National Foundation—March of Dimes)

Children in both groups were followed up closely for several years for occurrence of polio. The results were extremely gratifying. The vaccinated group had 80 to 90 percent fewer cases of polio than the unvaccinated group. In other words, the vaccine was found to be 80 to 90 percent effective.

Today Salk vaccine is given in three doses. The second injection is given two to four weeks after the first and the third injection, not before seven months after the second.

A chapter yet to finish. While the use of Salk vaccine has reduced the incidence of polio by as much as 90 percent, there are still paralytic cases, even among vaccinated people. There are also people who are immune to the effects of virus on the nervous system but harbor the virus in their intestinal tracts and are thus dangerous carriers of the disease.

These problems are being eliminated with the use of an oral virus vaccine developed by Dr. Albert Sabin of the University of Cincinnati. The Sabin vaccine is composed of live but weakened polio viruses. Since it is taken by mouth, it reaches the digestive system, where the virus is harbored in a carrier. Already tested in several million people, the Sabin vaccine is becoming another effective weapon in the war on polio.

Scientific methods. Throughout the history of the conquest of polio there are many examples of the use of a scientific method. A scientific method is a logical and orderly procedure of investigation. Such a systematic method of inquiry distinguishes scientific study from curious dabbling and hit-or-miss efforts to solve a problem. However, scientific methods are not magic formulas that always lead to a successful solution of a problem. On the contrary, the best planned and executed scientific experiment can and often does end in failure. But eventual success may come from numerous failures as the scientist analyzes each result and continues his investigation in a new direction. Often this new direction yields an even more important discovery than the scientist had expected originally.

Various methods are used in scientific study, as indicated by the nature of the problem. We shall consider two methods, both of which will be used in your course in biology.

The research method. The scientist plans an experiment and outlines his own procedure in the *research method.* It is the means by which new knowledge is acquired and new concepts are established. You will have opportunities to use the research method in many phases of your biology course. An experiment may be performed by the class, by a group, or by an individual in an area of special interest.

The steps a research scientist follows in investigating a problem are logical and orderly:

Defining the problem. Scientific research requires first of all an inquisitive mind and the ability to recognize a problem. In the conquest of polio, for example, Dr. Heine recognized the fact that the disease attacked the nervous system rather than the muscles. Landsteiner and Popper determined that polio is caused by a virus. In this way the nature of the disease was defined, so that further research could attempt to conquer it.

1-5 Joseph D. Locker won a scholarship in the Westinghouse Science Talent Search with his investigation of the effects of incubation temperature on chick embryos. (Westinghouse Electric Corporation)

How does a root absorb water from the soil? How does light influence the growth of a stem and cause it to bend toward the light? How does a nerve stimulate a muscle and cause it to contract? What controls the rhythmic contractions of a beating heart? All of these questions can be answered by means of well-planned experiments. Problems arise continually in the study of science, and new problems grow out of solutions. In this way successful research leads to new research.

Collecting information relating to the problem. The scientist does not set out to prove everything for himself. If this were true, science could not progress beyond the achievement of a single lifetime. Before resorting to experimentation, the research investigator makes use of significant data and information relating to the problem. This avoids duplication of effort and repetition of work already done. Thus, an extensive library of research papers, scientific journals, and reference books is a vital part of a research center. Your textbook and laboratory guide as well as supplementary readings will serve as sources of information in solving biological problems in your course.

Returning to our polio story, this phase of the research method was employed when Medin and Wickman studied the spread of polio epidemics in Sweden. From their collection of data they were able to conclude that human carriers spread the disease.

Formulating a hypothesis. When a problem has been investigated to the fringe of knowledge without solution, it becomes necessary to proceed further by means of experimentation. At this point the researcher uses creative thinking and imagination in determining a tentative solution or outcome. This possible result is called a ***hypothesis.*** It might also be called a scientific hunch, or an educated guess. However, while the hypothesis may seem to be a reasonable solution or result in the light of known facts, it cannot be accepted until proved. Thus, the research worker must be not only imaginative in establishing a hypothesis, but also open-minded in discarding it if necessary.

In the research on polio, the investigators' hypothesis was that if the polio virus could be isolated and cultured, a vaccine might be produced that would provide immunity to the disease. Enders' work with monkey kidney tissue paved the way for the testing of this hypothesis.

Experimenting to test the hypothesis. The scientist must set up an experiment in which the hypothesis will be either proved or disproved. All factors must be removed or accounted for except the one to be tested. We refer to this as the ***variable,*** or ***experimental factor.*** In other words the researcher must limit his experiment to the testing of but one condition — that involved in the hypothesis. Frequently an experiment is conducted in duplicate, with all factors the same in the second experiment except for the experimental factor. This second, or ***control,*** experiment demonstrates the importance of the missing experimental factor.

The trials of both gamma globulin and the Salk vaccine are excellent examples of controlled experimentation in research. The only variable in the Salk test was the vaccine. Remember that over a half million children serving as controls were given injections of sterile solution.

Observing the experiment. What does the experiment prove? What does it disprove? At this point the scientist must use critical observation. What are the results in relation to the hypothesis? In the research on polio, the results bore out the hypothesis that a vaccine could produce immunity. Often the experiment that does not work as planned yields results even more important than those expected.

Organizing and recording data from an experiment. Every phase of the experiment — the way it was planned and set up, the conditions under which it was conducted, significant observations during its progress, and the results — must be recorded accurately. These records may be in the form of notes, drawings, tables, graphs, or calculations. In modern research, data are often processed by means of computers. In the research on polio the results of the Salk test would have been of no value had the investigators not kept careful records of the results.

Drawing conclusions. Scientific data are valuable only when they are put to use. This is accomplished by drawing valid conclusions from an experiment. Such conclusions must be based entirely on facts proved in the experiment. Often a conclusion leads to the discovery of a principle or the understanding of a concept that can be applied to other situations. This may result in the solution of a problem not involved in the original experiment. The Sabin oral vaccine is, for example, an outgrowth of the research done for the Salk vaccine.

Accurate reporting of research methods, results, and conclusions. Results of scientific research are frequently published in papers and journals and become valuable contributions to scientific literature. This is a recognized obligation of research scientists. Through the literature, scientists the world over are kept informed of significant developments in their particular fields. This cooperative exchange of information saves effort, time, and money and greatly accelerates scientific progress.

Conducting a controlled experiment. We can illustrate the steps followed in the research method in a simple controlled experiment that you can conduct in the laboratory. The experiment will involve the growth and development of bean seedlings and will relate to one environmental factor, light. We may define the problem as follows: *Is light necessary for the normal growth and development of a bean seedling?*

Having defined the problem it would be well to examine various references in the library for information concerning the relation of light to plant growth and nutrition. Much has been written on the subject. However, you may not find a specific answer to your problem regarding bean seedlings.

At this point you formulate the hypothesis, or tentative answer to your question, and assume that *light is necessary for the normal growth and development of bean seedlings.* This hypothesis must now be proved or disproved by experimentation. The logical experiment would involve the germination and growth of two sets of bean seedlings — one set in a dark place and the other in full light.

Two beans are planted in each of six, three-inch pots filled with loose, sandy soil. Three of the pots are marked *experimental* and are placed in a dark cupboard or stockroom. The other three pots are marked *control* and are set on a window shelf or other location where they receive full light. The temperature should be as nearly uniform as possible in the two locations. All the pots must be watered regularly and uniformly throughout the experiment, which lasts about four weeks.

As the experiment progresses, accurate observations of the condition of each seedling must be made each day. The time of germination of each plant should be recorded. Other data to be obtained each day include the length and diameter of the stems, the number and size of the leaves, and the color of the plants. These data should be recorded in a table.

The experiment should show striking differences in the two sets of plants. Those grown in the light should have sturdy stems and large, healthy, green leaves, while those grown in the dark should have longer, more spindly stems and small, yellow leaves. These results would provide sufficient evidence to prove the hypothesis: *Light is necessary for the normal growth and development of bean seedlings.*

In a controlled experiment it is necessary to consider all possible factors, but to vary only one. In this experiment, light was the only factor that varied in the experimental and control plants. If any of the other factors had varied, the results would not have been valid. If, for example, the seeds in the dark set had been planted in clay rather than loam, one could not say whether the poor growth was due to lack of light or to poor soil. The reason for using several seedlings in each set was to permit an average of the results. Otherwise the difference in growth rate and condition of the plants could have been due to a defective seed or a weak plant.

While we may conclude from this experiment that light is necessary for the normal growth and development of bean seedlings, this statement immediately raises several more questions. How much light is required? We know that light consists of radiations of various wavelengths which appear as the colors of the spectrum. Does a plant require red, yellow, green, blue, and violet rays equally, or are certain colors absorbed more than others? We also know that plants are normally subjected to periods of light and darkness. Is a dark period important? Why is light necessary for the growth of green plants, such as beans? These are but a few of the questions that grow out of a basic experiment involving light and the growth of plants. The proof of one hypothesis leads to many more questions and more experiments.

The technical method. While research is a vital part of science, a far greater number of people are engaged in the allied area of technology. The ratio of technicians to research scientists has been estimated to be 20 to one.

The technician is not seeking to prove or disprove a hypothesis or seeking new knowledge. Rather, he uses established procedures to make accurate checks and verify results. The ***technical method*** involves several steps that may be summarized as follows:

1. *Follow an outlined procedure without variation.* The results are valid and reliable only if the procedure was followed accurately.
2. *Make accurate observations.* An error or an oversight might make the entire procedure worthless.
3. *Record and report all findings.* Again, the technician must be extremely accurate in recording all results of a procedure.

The research and technical methods are frequently combined in scientific investigation. For example, research scientists investigated the relationship of weakened or killed polio virus to immunity. This is a research problem. However, in testing the vaccine for effectiveness, they followed a standard procedure and applied the technical method.

The technical method is widely used in all branches of science. Technicians follow outlined procedures in checking the bacterial content of water, milk, and other foods, in identifying various bacteria, and in checking the strength of antibiotics and other drugs used in medicine. Your biology course will include many outlined technical procedures as, for example, when you prepare subjects for microscopic study, extract pigments from leaves, observe a muscle contraction, or dissect an animal to study its internal organs.

Pure and applied science. We often make a distinction between ***pure science***, or basic research, and ***applied science***, largely from the standpoint of the nature and purpose of the work. In pure science research is conducted for the sake of knowledge itself. Applied science makes practical use of this knowledge. For example, much research has been conducted in recent years on the effects of radiation on living matter. It remained for applied science to make use of the knowledge gained from the research in destroying cancerous tissue by means of radiation.

A biologist looks at life. There are many ways in which a biologist examines living organisms. First there is the matter of structure. The body of a sponge has little resemblance to that of an earthworm, and the structure of an insect is totally different from that of a fish or a frog. There is just as great diversity in the structures of a mushroom, a moss, a fern, and a seed plant. ***Anatomy*** is the area of biology devoted to the study of the structure of organisms. Knowledge of structure is in turn basic to an understanding of the functions of living things. This area of biology is known as ***physiology.*** Anatomy and physiology — form and function — are closely related. Either would lack meaning without the other.

No organism lives as an isolated unit apart from its surroundings. Conditions in the environment determine whether the organism lives or perishes. What are these conditions? Some, like water, light, and temperature are physical. Equally important are the other plants and animals that share the environment, some supplying needs and others threatening survival. Thus, a living society is a dynamic, interacting system. In the study of ***ecology*** (i-*kahl*-uh-je), the biologist determines the interrelationships of organisms and their surroundings.

For more than two centuries biologists have been grouping and classifying the organisms of the earth — plant and animal, large and small, simple and complex — into systematic groups. This has been an enormous scientific problem in the area of biology known as ***taxonomy.***

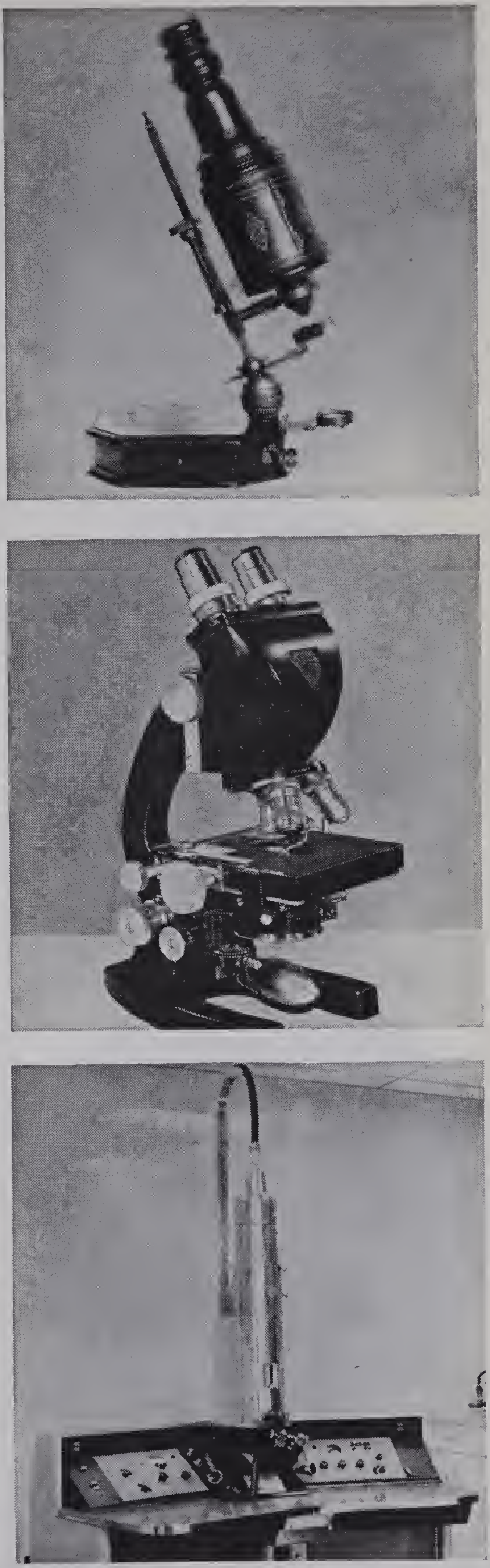
What sort of inner control causes a cow to produce more cows rather than horses or sheep, and why does a cow of a particular breed produce calves with the particular characteristics of its breed? You know, of course, that this is true, but do you know why? The answer to this question lies in an understanding of ***genetics,*** one of the most fascinating areas in the entire field of modern biology.

As you can see, biology is a complex science composed of numerous specialized branches, each examining life in a different way. A table giving many of these branches may be found in the Appendix.

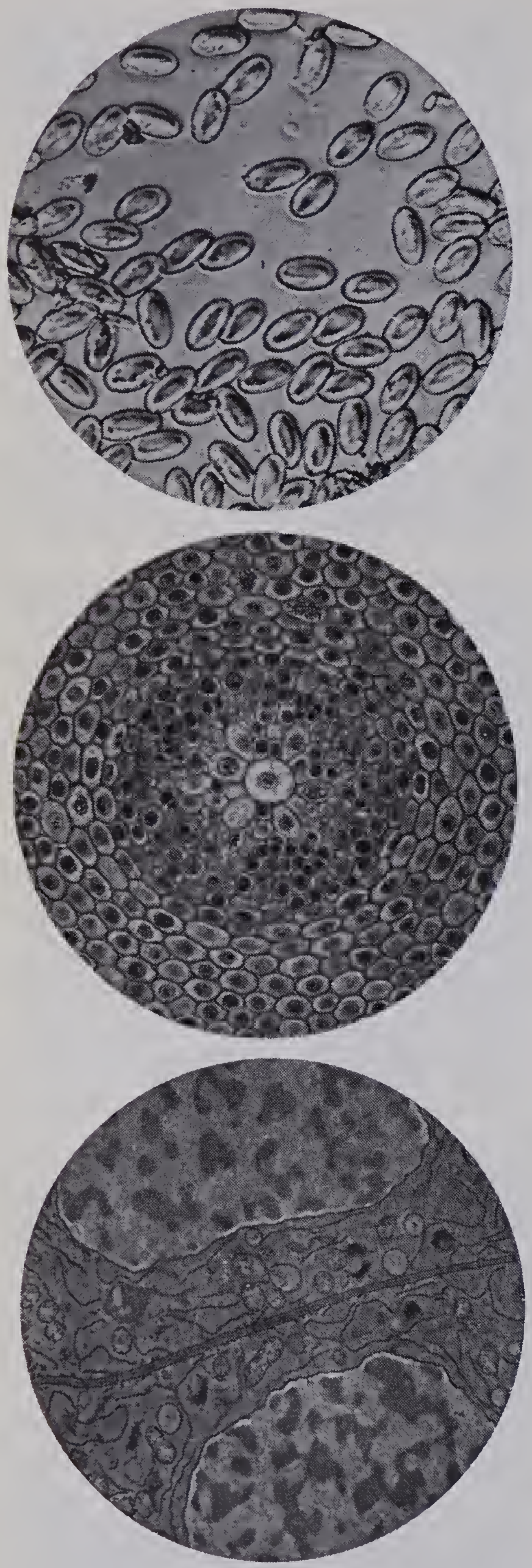
The biologist's principal tool – the microscope. It is difficult to say who actually invented the microscope. Since a single lens such as a magnifying glass is a simple microscope, we would have to go back to the Middle Ages for its inventor, for lenses capable of magnifying 10 to 20 times were ground during this period. However, we usually credit the compound microscope, using several lenses, and its first biological use to Anton Van Leeuwenhoek (*lay*-ven-hook), a Dutch lens grinder. Van Leeuwenhoek lived in Delft, Holland, 300 years ago (1632–1723). Microscope construction became his hobby. Altogether he is said to have made 247 different microscopes, each designed to examine a specific material.

One of Van Leeuwenhoek's early microscopes consisted of a tube for holding a small fish and a frame in which a magnifying lens was mounted. By holding the lens close to his eye, he could see blood surging through vessels in the tail of the fish. Other crude microscopes consisted of tubes with a lens mounted in each end. Thus, he used a lens to magnify the enlarged image of another lens. With a microscope built to examine pond water, he saw teeming microscopic animals, which he described as "cavorting beasties." With various perfections Van Leeuwenhoek's microscopes could enlarge materials 40 to 270 times. Thus, a Dutch lens grinder, pursuing a hobby, set the stage for one of the most important fields of today — the field of microbiology.

The modern compound microscope. The compound microscope has been improved steadily since the time of Van Leeuwenhoek. Improved lenses providing greater magnifications and precision mechanical parts are incorporated in the microscopes we use today. An



1-6 Top, a very early microscope; middle, a modern compound optical microscope; bottom, an electron microscope. (Bettmann Archive; Bausch and Lomb, Inc.; RCA)



1-7 Top, photomicrograph of pigeon blood taken in 1871; middle, onion root cells with a modern compound optical microscope; bottom, an electron micrograph of parts of two onion root cells. (Armed Forces Institute of Pathology; General Biological Supply House, Inc.; K. R. Porter—*Scientific American*)

instrument such as those in your high school laboratory is shown in Fig. 1–6. This light, or optical, microscope contains several sets of magnifying lenses. One set is in the *eyepiece,* or ocular, through which the observer views the magnified materials. Other lens systems are contained in *objectives.* Microscopes have from one to four objectives. These, in combination with eyepieces of varying magnifications, give different degrees of enlargement. Light is received by a mirror and is directed through the lens systems to the observer's eye.

A standard microscope, used in most high school laboratories, usually provides a low power magnification of 100 times and a high power magnification of 430 or 440 times. These magnifications reveal cells and many microscopic plants and animals. Bacteria and other extremely small organisms, as well as smaller cell structures, require greater magnification. This is provided in a special objective that provides an enlargement of 1,000 to 1,500 times, depending on the eyepiece used with it. Such bacteriological, medical, and research microscopes are high-precision instruments with extremely sensitive optical systems and mechanical parts.

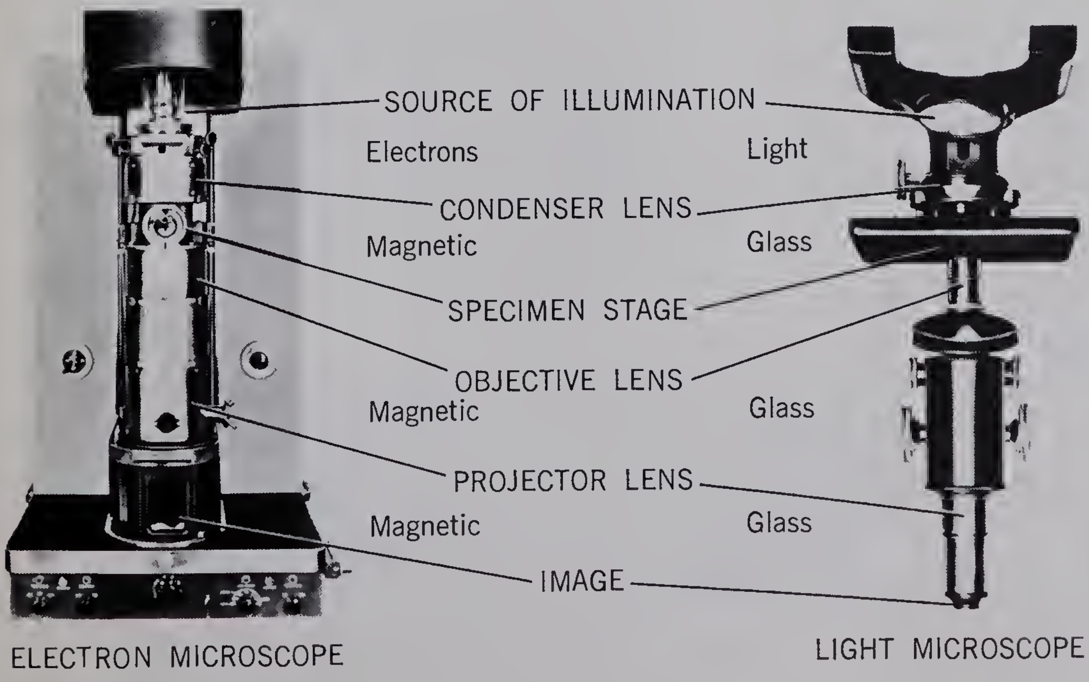
Limitations of the light microscope. You may wonder why, in this age of precision instruments for nearly every use, it is not possible to build a light microscope with a magnification much greater than 1,500 times. It is true that we could produce the lenses and the mechanical parts for such a microscope. However, the problem lies in the properties of light itself.

Two factors must be considered in the use of a microscope. One is *magnification,* or the enlargement of an image. The other is *resolution,* or the providing of a visible image in which details can be seen. As light rays pass through material on a microscope stage, they reflect from surfaces of the material. This produces an image. The light then passes through the lenses of the objective and the eyepiece. Each lens bends the light rays, thus spreading them apart. This forms the magnified image that reaches the observer's eye. The greater the magnification, the more the rays are bent and spread. This reduces the amount of light that reaches the observer's eye and decreases the resolution. You will notice the difference in the brightness of the field and the resolution under low power (100X) as compared with high power (430 or 440X). There is a limit to which light rays may be spread and still produce an image with sufficient resolution to be visible. This is a magnification of about 1,500 to 2,000 times.

You might compare this problem with the magnification of a newspaper picture. Without magnification, the picture is clear and the details are sharp. If you view it through a reading glass, you see that the picture is made up of small dots. Now, if you use stronger and stronger lenses, the dots appear farther and farther apart. Finally, so few are visible that the picture is lost.

The electron microscope. An entirely new principle of magnification allowed the biologist to explore a realm of ultramicroscopic particles that the light microscope had never revealed. This was the electron microscope. This remarkable instrument substitutes streams of electrons for light.

Figure 1–8 shows a comparison of a light and the most recent electron microscope. We shall follow the electron beams from the energy source to the view plate on which the highly magnified image appears. A very fine tungsten wire is heated by an electric current to a temperature of 2,000° C. This produces a cloud of electrons that boil off around the wire filament. The electrons are then accelerated into a vacuum chamber by an electron gun. The chamber through which the electrons stream must be nearly free of air molecules with which the electrons would collide. As the electrons enter the vacuum chamber, they pass through two electromagnets. The material to be examined is mounted on fine copper wire mesh. The electron beam passes through the material on the wire mesh



1-8 The electron microscope compared with a modern light microscope. (RCA) and enters the electromagnets. Both of these bend the electron beams and produce high magnifications. The beams are invisible and are dangerous radiations if contacted by the operator. However, when they strike a phosphorous-coated view plate enclosed in leaded glass for safety, they produce a visible image. Frequently the image on the view plate is photographed for more detailed study. Photographic plates are inserted below the view plate. The electrons penetrate the photographically sensitive substance on the plate. This photographs the magnified image just as you would take a picture with a camera. Prints made from the plate negatives may be enlarged to make extremely fine details visible to the eye. But no details will appear in the enlargement that the electron microscope did not record.

With one electromagnet the instrument magnifies from 1,410 to 32,000 times. Thus, the lowest magnification of the electron microscope overlaps the highest magnification of the light microscope. By changing the electromagnet it is possible to reach a magnification of 100,000 to 200,000 times. If this image is enlarged five times photographically, an object in a print appears 1,000,000 times its actual size.

IN CONCLUSION

Biology has probably progressed more rapidly in the last 20 years than it did in the previous 20 centuries. This progress is due largely to the fact that the electron microscope and biochemical procedures have brought the science to the molecular level, at which all living things have much in common.

Biology, like all of science, is an organized body of knowledge gained from experimentation and objective observation, considered to be true and reliable but subject to change and revision in the light of new discoveries. Biology is also a method of inquiry and problem solving involving several procedures for investigation. The conquest of polio affords a dramatic example of the success of scientific methods.

The controlled experiment narrows a procedure to the testing of a single variable or experimental factor involved in the hypothesis. The experiment is accompanied by a control, in which all factors except the experimental factor are duplicated.

The biologist looks at life from many different standpoints: structure, function, interrelationships with the environment, classification, and hereditary mechanisms are but some examples of approaches in biology.

In the next chapter we shall attempt a general definition of the phenomenon of life — what makes living things different from nonliving things?

BIOLOGICALLY SPEAKING

anatomy
applied science
control
ecology
experimental
genetics
hypothesis
physiology
pure science
research method
taxonomy
technical method
variable

QUESTIONS FOR REVIEW

1. Give several examples of scientific achievements that illustrate the international aspects of science.
2. List examples of the influence of progress in areas related to biology to advances in the biological sciences.
3. Describe the contributions of Heine, Medin, Wickman, Landsteiner, Salk, and Sabin in the conquest of polio.
4. How was a scientific control involved in the testing of gamma globulin?
5. How is the Sabin polio vaccine different from the Salk vaccine?
6. Describe the steps of the research method.
7. What is a hypothesis?
8. We often think of research as centering in the laboratory. Why is a library equally important?
9. What is the purpose of a control in scientific experimentation?
10. Why is the reporting of methods, results, and conclusions an important part of scientific research?
11. Give several examples of application of the technical method.
12. Distinguish between pure and applied science.
13. Using a tree as an example, explain how a biologist might examine it from the standpoint of anatomy, physiology, ecology, taxonomy, and genetics.
14. Describe one of Van Leeuwenhoek's early miscroscopes.
15. Locate the lens systems in a modern compound microscope.
16. Distinguish between magnification and resolution of a light microscope.
17. What energy source is substituted for light in an electron microscope?
18. How is the enlarged image received in an electron microscope?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the integral relationship of academic freedom and scientific pursuits.
2. In what ways is science incompatible with superstition?
3. Discuss the ways in which progress in biology has paralleled the perfection of the microscope.
4. Why is it important that a scientist be willing to recognize his own limitations as well as those of science generally?
5. What stages in the conquest of polio illustrate scientific cooperation on a worldwide basis?
6. Outline a controlled experiment designed to test a single experimental factor.
7. Compare the research and technical methods from the standpoint of purpose and procedure.
8. Discuss the principles of an electron microscope that overcome the limitations of the light microscope.

CHAPTER 2

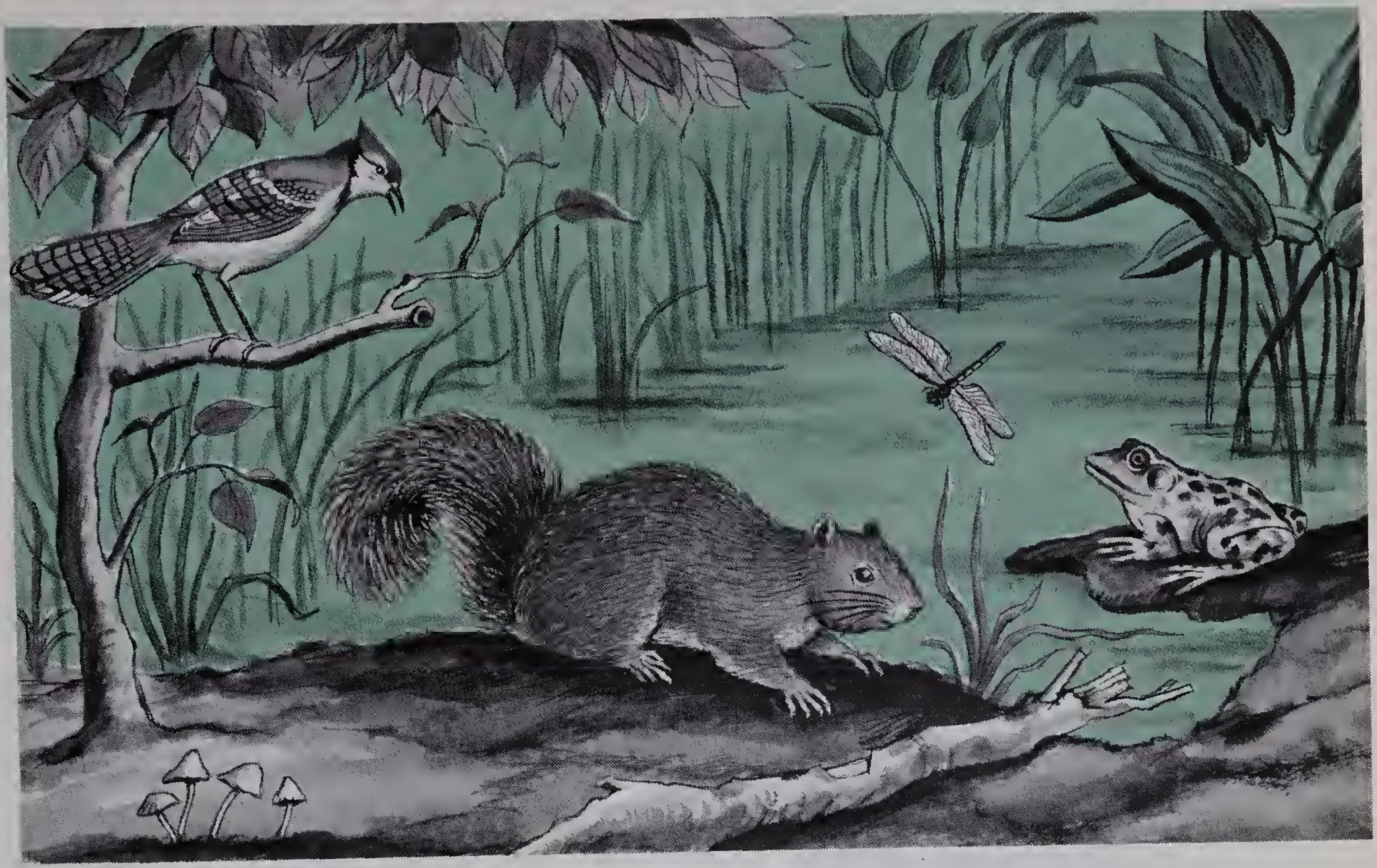
THE LIVING CONDITION

The living and the nonliving. What is life? How did it originate? As a first step in investigating the living condition, we shall make some basic comparisons of living and nonliving things. Fig. 2–1 shows a natural setting in a shallow pool at the edge of a woods. A frog is sitting on a rock while a dragonfly hovers overhead. A bluejay, perched on the branch of a shrub, is watching the squirrel on the ground. Several mushrooms have pushed through the moist soil. Several kinds of aquatic plants are growing in the shallow water of the pool. It is no problem to separate the living things from the nonliving in this scene. The plants and animals are ***organisms.*** That is, they are complete and entire living things, composed of living substances and performing life activities. The soil, the water, and the rock are nonliving. Their substances are different and they lack the life activities of the organisms.

Isn't it true, however, that the materials composing the organisms came, directly or indirectly, from the soil, air, and water. It is also true that when the organisms die, they will decompose and return to nonliving substances. Thus, living substances and nonliving materials of the earth have a close relationship. To distinguish one from the other, we must consider differences in origin, chemical composition, structure, and function. Let us take a closer look at living and nonliving things.

Life is self-perpetuating. Life arises from life. Biologists call this the principle of ***biogenesis*** (*by*-oh-*jen*-i-sis). The bluejay shown in Fig. 2–1 began its life as a fertilized egg from which it developed and hatched. A tiny mass of living substance no larger than a pinhead developed into a new organism. However, this substance did not originate in the egg. It was contributed by the parent birds. In this manner the life of the parents is perpetuated in the offspring. The same can be said of the squirrel, the frog, and the dragonfly. Similarly, the original substance of the grass came from seed that was formed from materials of the parent plants.

You might compare this perpetuation of life to the lighting of a new fire from one which is burning. If a fire goes out, the flame is lost and is not rekindled. This can be compared with the death of an organism. But if new supplies of fuel are lighted from burning fires, the flames can be preserved endlessly. Could it be, then, that the original life of the earth still exists in all of the forms in which we find living organisms today? Certainly, living organisms have not arisen suddenly from non-



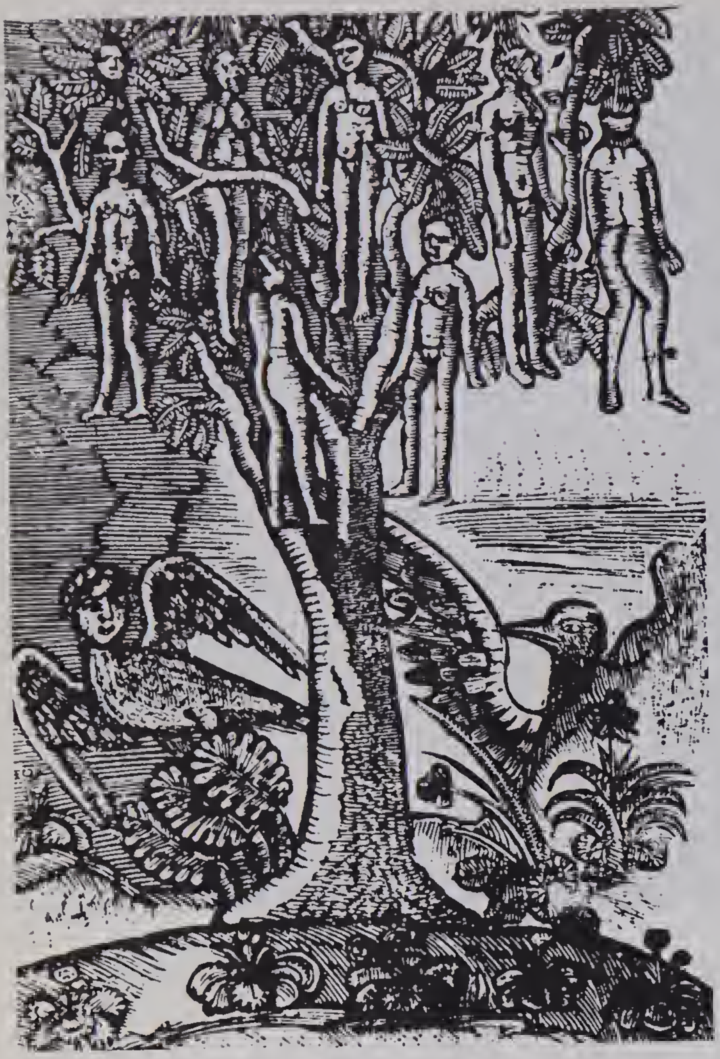
2-1 Name the living and nonliving things shown in the drawing. Explain why you classify them in these two groups.

living materials. *Life comes only from life.* Would it surprise you to learn that this concept of biogenesis is a rather recent concept?

The myth of spontaneous generation. From ancient times until less than a century ago, people generally believed that certain nonliving or dead materials could be transformed into living organisms. We refer to this belief as *abiogenesis* (*ay*-by-oh-*jen*-i-sis), or ***spontaneous generation.***

The ancients were familiar with the hatching of birds from eggs and with the birth of larger animals such as mammals. However, they knew little or nothing about the growth and development of smaller animals such as insects and worms. Animals of this sort were linked with stories of spontaneous generation.

The Roman poet Vergil outlined a recipe for producing insects from mud. It was generally believed that decaying meat changed to maggots, which later became flies. One of the most astounding accounts of spontaneous generation came from Jean Van Helmont about three centuries ago. Van Helmont outlined a method of producing mice from grains of wheat and human sweat. According to his directions a dirty shirt placed in a container with grains of wheat would produce mice in 21 days. Supposedly the mice were formed from the fermenting wheat, while the human sweat in the dirty shirt provided the "active principle" necessary for the process. Other accounts of spontaneous generation are equally interesting and amazing. Frogs and fish were thought to be generated in clouds during a thunderstorm and fall to the earth with rain. Honeybees supposedly came from the decaying carcasses of animals such as horses. Actually, these insects were flies that resemble honeybees and they came from maggots that hatched



2-2 This drawing of the legendary Wak-Wak tree of the South Pacific, which bore human fruit, appeared in a Turkish history book published in 1730. (Bettmann Archive)

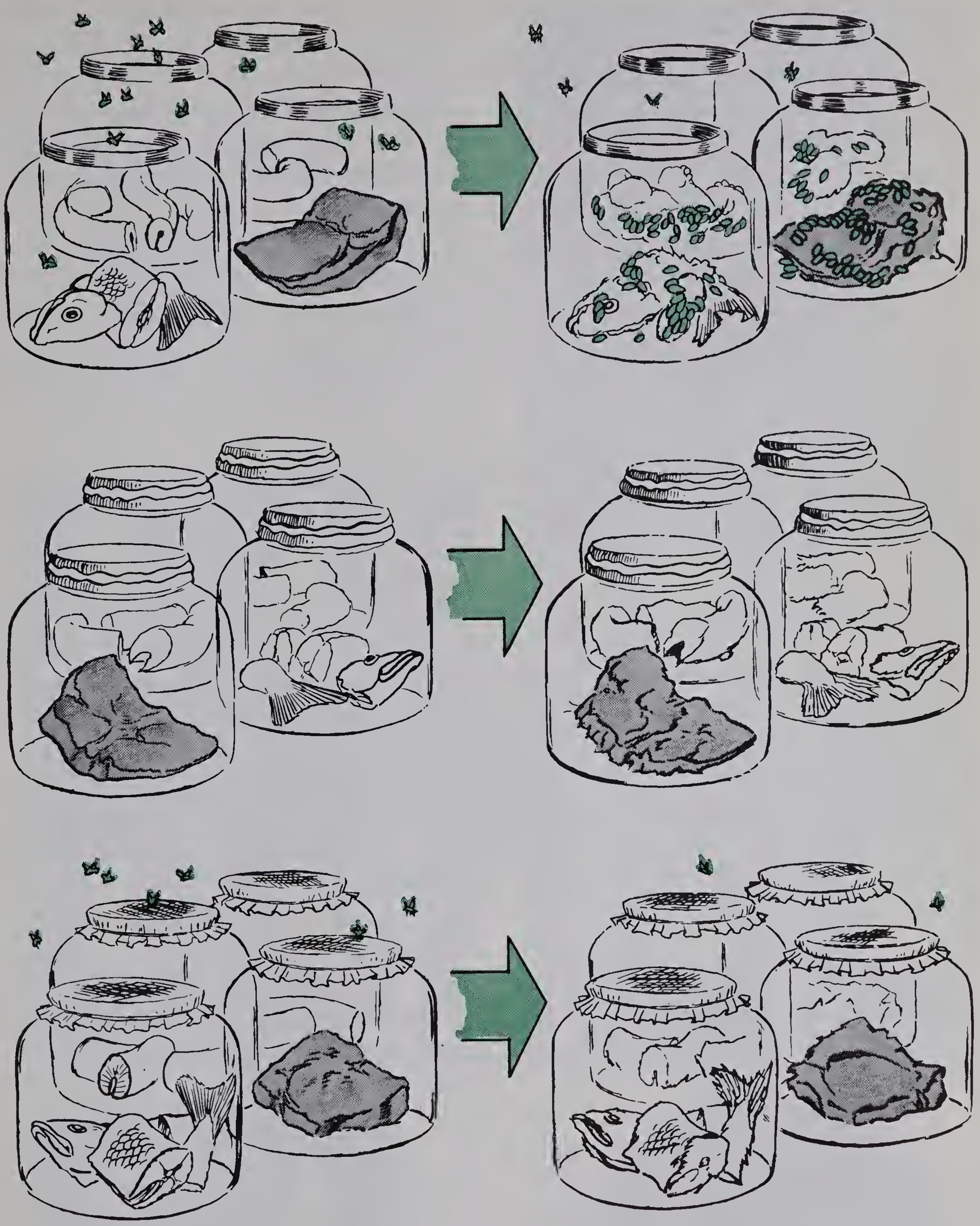
from eggs laid in the carcass. However, for centuries, no one observed this egg laying, and the theory remained unchallenged. According to another superstition, geese were formed from barnacles attached to wrecked ships.

Redi's blow to spontaneous generation. From ancient times until late in the 17th century, the best minds accepted the theory of spontaneous generation without question. No one had ever proved that spontaneous generation could occur, but at that time demonstrated facts were not necessary for drawing conclusions. However, Francesco Redi (*ray*-dee), a 17th century Italian scientist, demanded more than theory and supposition for his views on spontaneous generation. Can decaying flesh form flies? Redi said no. Redi claimed that flies came from eggs laid by flies and that the decaying meat provided nothing more than nourishment for the maggots.

To prove his theory Redi conducted an experiment in the year 1668 which would be considered reliable even by the standards of modern science. According to his own detailed account of the experiment, Redi placed some pieces of snake, some fish, some "eels of Arno," and a slice of milk-fed veal in each of four clean jars. He then prepared a duplicate set of four jars. One set of jars was left open. The other, which we would designate as a control today, was covered and securely sealed with wax. Flies were soon attracted to the open jars, which they entered to lay eggs. Within a short time maggots appeared in all of the open jars. Several weeks later Redi opened the sealed jars and found putrefied meat but no maggots. On the basis of evidence from the experiment, Redi concluded that flies originate from flies and not from decaying meat by spontaneous generation.

Had he stopped at this point, however, his critics would have argued that air was necessary as an "active principle" in spontaneous generation. It was true that the sealed jars did not admit air. Thus, Redi's first experiment involved not one, but two variable factors — air and flies.

In a second experiment Redi prepared four jars with the same materials as before and covered each with a fine cloth he called "fine Naples veil." Air passed through the cloth freely, but flies could not enter the jars. As the meat decayed, flies gathered on the cloth covers and laid eggs, but no maggots appeared in the decaying meat. In this second experiment Redi supplied

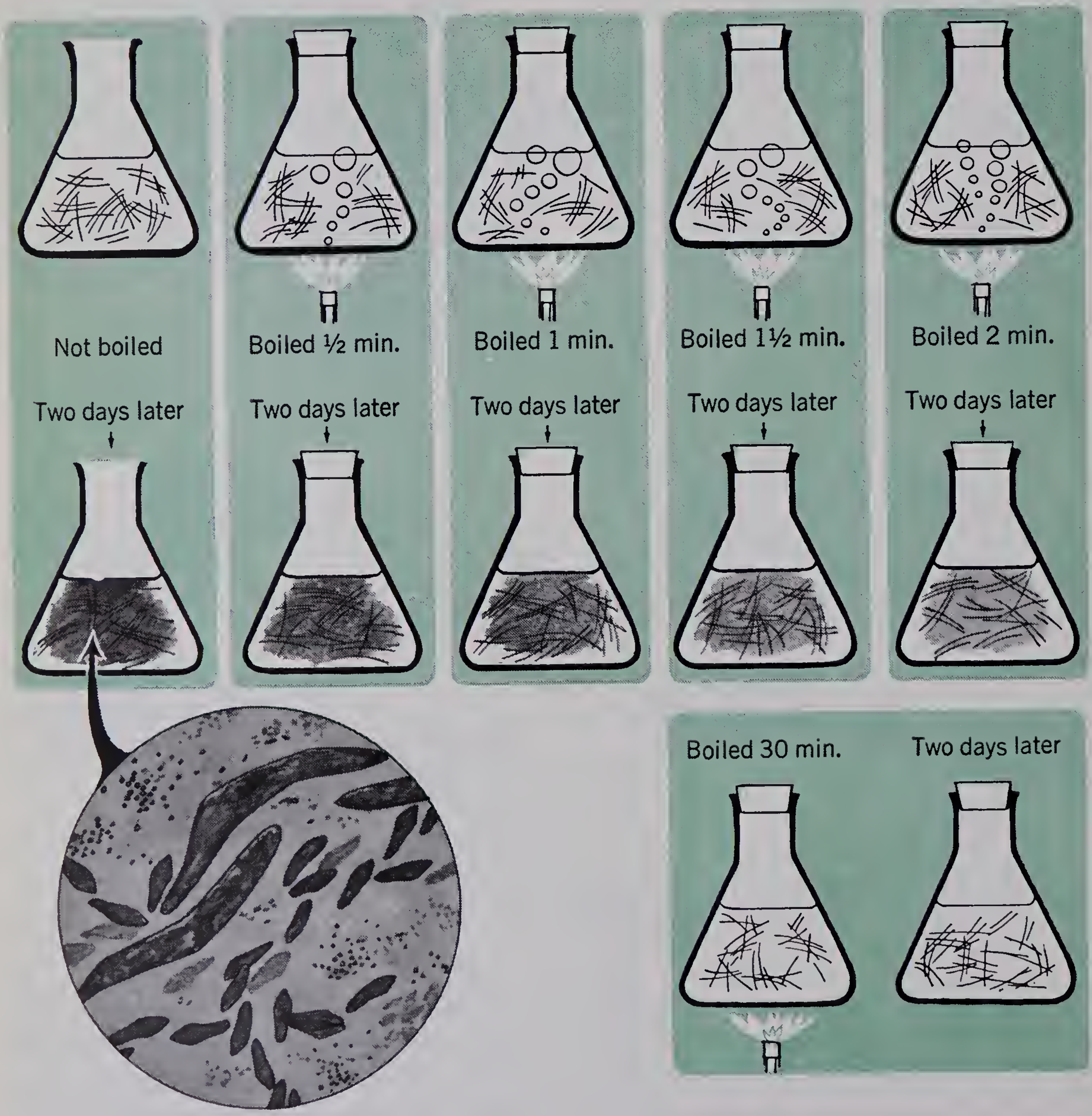


2-3 Redi's controlled experiment showed the relationship between flies and the occurrence of maggots in rotten meat.

the convincing proof that flies come only from flies. Did Redi's work disprove spontaneous generation? You might think so, but this theory was to remain in general acceptance for more than two centuries after Redi. True, Redi had proved that flies come only from pre-existing flies and this might apply to other insects, but he had not proved that worms and other lowly animals do not originate by spontaneous generation.

Microorganisms and abiogenesis. With the development of the microscope, 18th century biologists found various broths and sugar solutions to be swarming with microorganisms. This presented a new problem in disproving spontaneous generation. Where had these organisms come from if not from the broths? Two schools of thought developed to explain the origin of microorganisms. One group supported spontaneous generation as the only possible answer. The other insisted that bacteria and other organisms could come only from pre-existing organisms. Remember that biologists in this day had no idea that bacteria grow and reproduce and that they are abundant everywhere.

One of the supporters of the theory of spontaneous generation of microorganisms was the English scientist John Needham (1713–1781). Needham prepared mutton broth in corked


Not boiled
Boiled ½ min.
Boiled 1 min.
Boiled 1½ min.
Boiled 2 min.
Two days later
Two days later
Two days later
Two days later
Two days later
Boiled 30 min.
Two days later

2-4 Spallanzani's hay-infusion experiment showed the flaws in the hypothesis of spontaneous generation.

flasks which he boiled for a few minutes. After a few days he examined the broth with a microscope and found it to be teeming with microorganisms. When he repeated the experiment with various meat and vegetable broths, the results were the same. Needham argued that boiling had destroyed all life in the broth and, since the flasks were closed with stoppers, the organisms present after standing must have been formed by spontaneous generation.

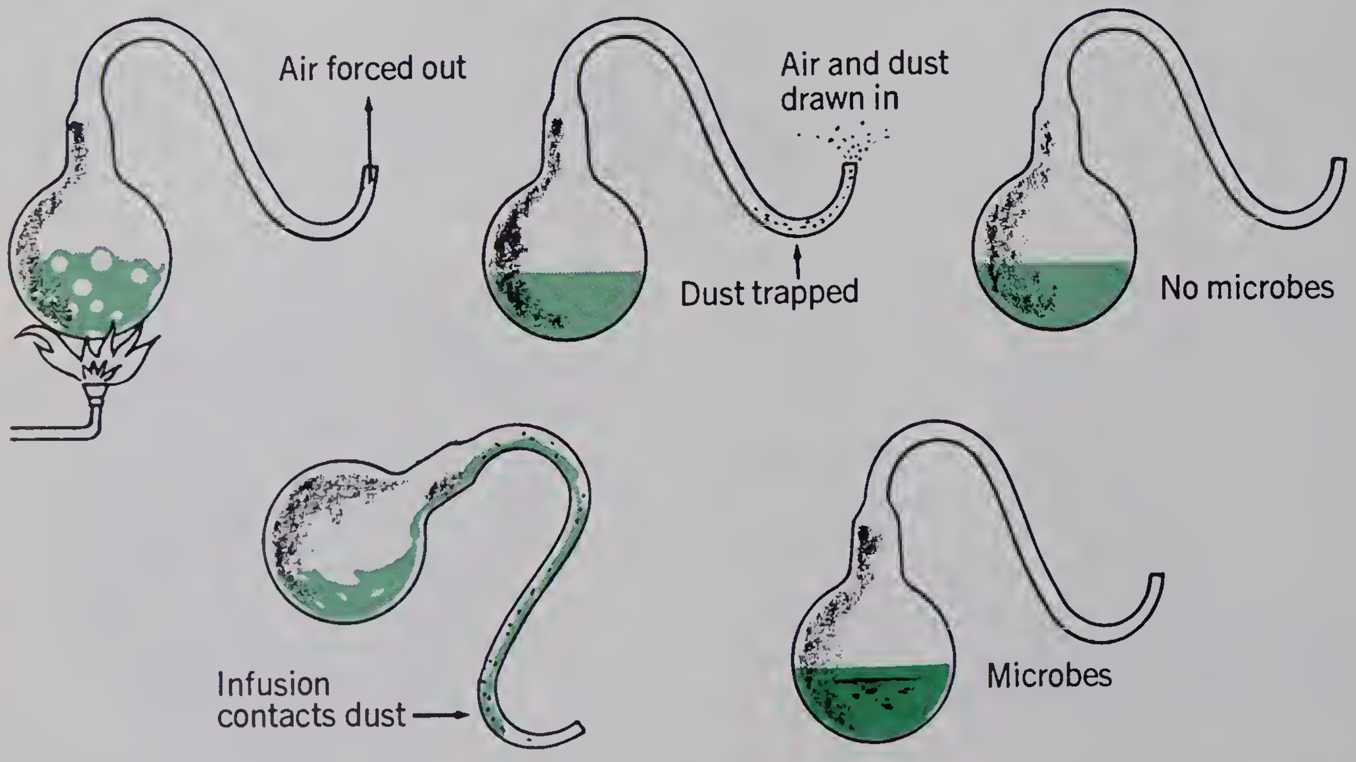
Lazzaro Spallanzani (1729–1799), an Italian scientist, led the opposition in the attack on Needham's conclusions. He boiled seeds in water for 30 minutes. Such a mixture of organic material and water is called an *infusion*. Spallanzani's infusions were prepared in loosely stoppered flasks that air could enter. Microorganisms appeared in them as they had in Needham's broth. This led him to further investigation in which he used a series of five flasks containing seed infusion. One flask was left open. Four were sealed and boiled; one for a half minute, one for one minute, one for one and a half minutes, and one for two minutes. After two days Spallanzani examined all of the infusions with a microscope. He found the infusion in the open flask to be teeming with bacteria. The four sealed flasks also contained bacteria, but in much smaller numbers. However, the number of bacteria in the sealed flasks decreased as the boiling time was increased. This was a significant observation. If boiling the infusion for two minutes reduced the number of bacteria to the lowest in the series, would not a longer boiling time prevent any organisms from growing? To test this assumption Spallanzani prepared additional infusion and boiled it in sealed flasks for 30 minutes. No microorganisms appeared in these flasks as long as they were sealed from the air. However, if the flasks were opened, microorganisms appeared in the infusion within a few days. To Spallanzani this was proof that the microorganisms came from the air, not from the infusion by spontaneous generation. But this did not satisfy the opposition who now claimed that the boiling had spoiled the "active principle" in the air necessary for spontaneous generation. Thus the argument continued for another 50 years.

2-5 Spallanzani (standing) also conducted experiments with birds. (Bettmann Archive)

Pasteur's decisive defeat of spontaneous generation. It remained for Louis Pasteur (1822–1895), a French chemist, to deal a final and convincing blow to the theory of spontaneous generation. As a young man Pasteur was engaged in studies of fermentation and the chemical changes that occur as sugars are converted to alcohol. He had observed the many yeasts and other microorganisms present in fermenting fruit juices and sugar beet juice and found that the number of organisms increased as fermentation progressed. Pasteur was convinced that the microorganisms associated with fermentation came from the air and that dust particles, grape skins, and all other materials exposed to the air harbored great numbers of bacteria, yeasts, and other minute organisms. In testing this hypothesis Pasteur carried out several experiments which, while simple, were so well planned and convincing that they could not be refuted by even the strongest supporters of the theory of spontaneous generation.

In his first series of experiments, he used a variety of liquids which would support bacteria and other microorganisms if exposed to the air. These included an infusion of yeast in water, brewer's yeast, sugar and water, and sugar beet juice. Each of these liquids was sealed in a long-necked flask and boiled for several minutes. He then took the sterile flasks to a variety of places in which the air contained different amounts of dust. Flasks opened along dusty roads were quickly contaminated as evidenced by abundant growth of microorganisms within a few days. However, flasks opened on hills and mountains showed much less growth of microorganisms. These results bore out his theory that bacteria and other organisms were present in the air with dust particles.

It now remained for Pasteur to prove his theory under the controlled conditions of his laboratory. This experiment involved his famous swan-necked flasks. Again he prepared a liquid containing sugar and yeast and poured it into a long-necked flask. He then heated the neck of the flask and bent it into an S-shaped curve resembling a swan's neck. After preparing the flask, he boiled the liquid for several minutes. Air forced out of the flask during the boiling returned through the neck as the liquid cooled. Throughout the experiment air moved through the open neck. Water and dust particles, however, settled in the trap formed by



2-6 Pasteur's experiment with swan-necked flasks convinced most biologists that spontaneous generation does not occur.

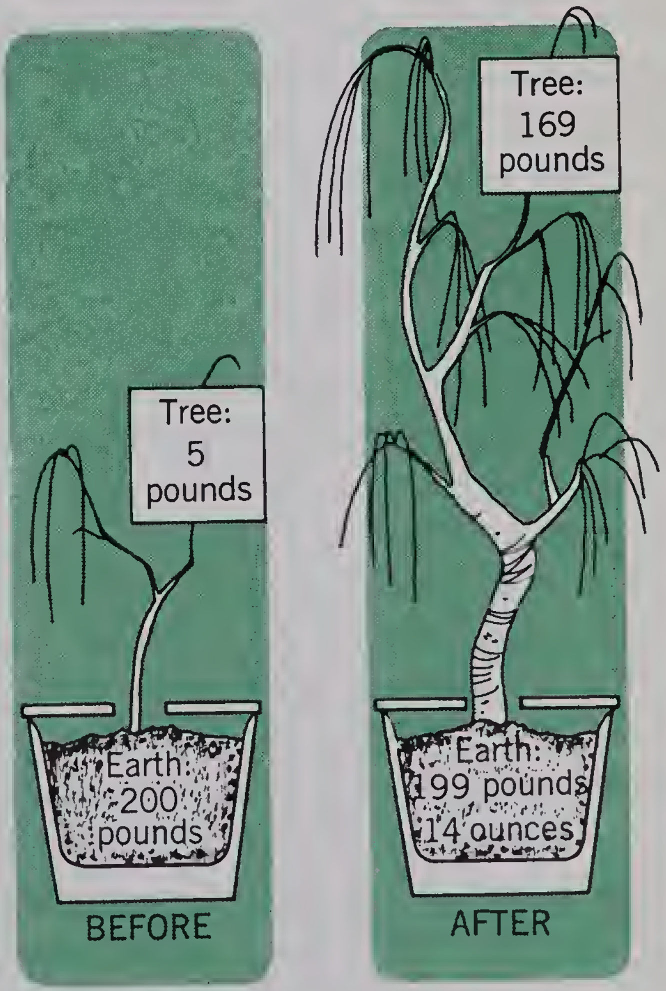
the bent neck. Even though the sugar solution was in direct contact with the outside air, no organisms appeared in the liquid in the flask. Pasteur found that such a flask would remain sterile for more than a year. But if the flask was tipped to allow the liquid to flow into the bent neck and contact the trapped dust, microorganisms appeared in the flask in great numbers within a few days.

Thus, Pasteur's simple experiment with his swan-necked flasks refuted all of the arguments his opponents could advance. Boiling had not destroyed the property of the liquid in the flask to support microorganisms, nor had the experiment excluded the "active principle" of the air thought to be necessary for spontaneous generation. Both the liquid and the air in the flask were suitable for the growth of bacteria, molds, and other organisms if they were introduced from an outside source.

So it was that Louis Pasteur substituted a proved and valid concept, biogenesis, for a theory which had been accepted for centuries without any real evidence. Life comes only from life. Experimental evidence has borne this out from the time of Pasteur to the present day. However, we cannot assume that abiogenesis has never occurred, nor that it could never happen again. How did life begin in the first place? Will a biologist some day assemble just the right nonliving materials in a test tube and organize living matter? Is a virus particle a form of matter which fluctuates between the nonliving and the living condition? While we accept biogenesis as a fundamental property of the living condition, we must keep these exceptions in mind and explore them further at a more appropriate time.

Living things have a unique chemical organization. Only in living organisms do we find the organized activity of a complex system of substances that we refer to as life. We often speak collectively of this system of substances as ***protoplasm.*** And we would be correct in saying that only living organisms organize protoplasm.

At one time biologists thought that protoplasm was actually a living substance. Today we know that it is not a substance in the sense that water, salts, sugars, and acids are substances, nor is it living. Furthermore, none of the substances composing protoplasm are living. However, when certain proteins, carbohydrates, fats, and other substances are organized into a system by a living organism, a state of chemical activity we call a living condition is established.



2-7 From this experiment, performed in the 17th century, van Helmont concluded that the living matter of the tree came entirely from water. Of what substance was he unaware?

If you analyze the protoplasm of numerous plants and animals you will find basic similarities in the substances present. In this respect protoplasm is a unifying characteristic of all organisms. But while there are similarities, there are almost limitless variations in protoplasm. It differs in every kind of organism. It even varies in individuals. The materials in your protoplasm are not exactly like those of any other person, unless you have an identical twin. Furthermore, these materials are constantly changing. You can see, then, why protoplasm is an indefinite and elusive word. It is still a good biological term, however, as long as you use it properly — not as a definite substance and not as a living material, but as a complex, continually changing system of substances which establishes the living condition.

Living things have a constant energy requirement. All chemical activities require energy. Since life is basically chemical activity, it requires a constant source of energy. As you will learn, almost all of the energy used by living things comes ultimately from the sun. Both plants and animals obtain energy more directly by the breakdown of complex chemical substances we call foods. The energy released in this way is in turn used to support other chemical and phvsical processes. Life continues only as long as these energy transformations occur.

Living things have a cellular organization. If you conducted a microscopic survey of a large number of organisms and parts of organisms, you would discover that regardless of size and complexity, they are all composed of cells — one cell, a few cells, or billions of cells. Cellular make-up is peculiar to organisms. Because cells enter into the make-up of every organism, they have been referred to as the *common denominator of life.* As you study diverse organisms from bacteria to seed plants and ameba to man, you will deal continually with cells. Some will be relatively simple in organization and others will be highly specialized. But the various substances associated with the living condition are always organized in these basic structural units.

Cells may remain for some time after the death of an organism. Thus, we cannot say that the presence of cells is evidence of a living condition. However, we can say that cells are a product of living organisms and that they are never organized in nonliving materials.

If cells are basic units of organisms, then what about the viruses? Are they organisms? Are they living? When you deal with the composition of viruses in Chapter 15, you will discover that virus particles are not cells. They are subcellular, or below the level of cells in composition. However, they have certain chemical properties that are found only in living cells. Perhaps the viruses are a link between living organisms and nonliving substances. We shall explore this possibility more fully in Chapter 15.

Living organisms are capable of growth. At least for a time, living organisms grow by enlargement. So do crystals and icicles and they are, of course, nonliving. Is it correct, then, to refer to growth as a characteristic of the living condition? First we must determine just what we mean by growth.

An icicle hanging from a roof may increase in size as water trickles over its surface and freezes before dripping off. This kind of enlargement is growth by external addition. The same would apply to a crystal growing in a solution.

The growth of a living organism is entirely different. A tree does not grow by taking more of its own substance from the soil and atmosphere and adding it to the material already present. Nor can you say that you grow by adding food to your body or your body is an accumulation of the foods you have eaten.

There are many complex chemical processes involved in the growth of an organism. During these processes large and complicated molecules are formed. As a result of these biochemical activities, substances quite unlike those composing nonliving materials are incorporated in the make-up of living organisms. Thus, living things do not accumulate their substance — they organize it, or *assimilate* it.

Perhaps you question the reference to growth as a characteristic of the living condition. Plants and animals may continue to live long after growth has apparently ceased. However, the substances composing organisms are only temporary. Replacement must occur continually. Thus, growth and maintenance without enlargement continue throughout life.

Living things have a definite form and size range. You can describe a black bear, a jack rabbit, a rainbow trout, a sugar maple tree, or a Douglas fir with reasonable accuracy. With some variation, your description will fit all others of the same kind. Furthermore, you can predict the approximate size each will attain at maturity. On what do you base these descriptions and predictions of size? No doubt you would be amazed to see a rainbow trout weighing 200 pounds or a maple tree towering 300 feet in a forest. Some fish reach this size, and so do some trees. However, you expect a plant or animal to resemble its parents both in form and in size at maturity. Have you wondered why? Perhaps you would say that size and form are determined by heredity. It might be more accurate to say that they are determined by substances called *genes*. Genes cause the rainbow trout to develop a particular form of fins, a certain body form, and a distinctive coloration. All fish have genes, but only rainbow trout have the particular gene structure and combinations which, when transmitted to offspring, regulate the development of young rainbow trout.

Like produces like — we are all familiar with this concept. But only in recent years have we understood how genes operate in heredity. You will find out much more about the composition and regulatory functions of genes in your study of genetics.

Living organisms have a life span. A rock you pick up may be a million years old. And it may remain in its present condition another million years or more. The substance composing the rock is quite a contrast to the substances composing an organism. Life is activity. When conditions are no longer favorable for this activity, life ceases. Thus, all organisms have a definite period of existence which we refer to as the ***life span.*** We may divide this period of existence into periods or stages, as follows: 1. beginning, or origin; 2. growth; 3. maturity; 4. decline; and 5. death.

A period of rapid growth follows the formation of an organism. This growth period may last a few minutes, a few weeks, several months, or many years, depending on the organism. As the mass of the plant or animal increases during its period of growth, the rate of growth decreases. Finally maturity is reached. During this period growth is reduced to repair and replacement of vital substances. Eventually the organism reaches a point at which repair or replacement of damaged or broken-down materials is impossible. This marks the period of decline, or senility, which is followed inevitably by death.

How long may a plant or animal survive? Here we find great variations. Furthermore, we find that the life spans of organisms are for the most part regulated by factors or conditions predetermined. That is, barring disease or accidental death, the life span of any particular plant or animal is about the same as all others of its kind. The petunia, marigold, and zinnia plants of your flower garden grow, reproduce, and die in a single season. On the other hand, a white oak tree may live 500 years. A "big tree" (*Sequoia gigantea*) of California would still be young at this age. These remarkable trees may live several thousand years.

Certain insects live but a few weeks. Five years is old for some fish. Five to 10 years is the normal life span of a chicken. Horses may reach an age of 30 or more. The average life span of man is 68 to 70 years, but may be extended to 100 years or more in a few generations.

We may say that a definite life span distinguishes living organisms from nonliving materials. Is a life span a positive limitation of the living condition? If an organism can grow and maintain its substances part of its life, why can't it live indefinitely? Perhaps it could, if certain changes could be avoided. In your study of biology, you will deal with various one-celled organisms. Among these are bacteria. An individual bacterium may be formed and mature in half an hour or less. At this point it splits into two bacteria, both of which are immature and capable of growth. Thus, a bacterium never dies of old age as long as conditions are favorable for growth and reproduction. The same applies to the ameba and other one-celled animals. Perhaps you have already reasoned that an ameba you see today is part of the first ameba which ever lived.

Continued growth becomes a problem when organisms become larger and many-celled. When a certain size is reached, growth ceases and decline is inevitable. Would it be possible, then, to remove part of a larger organism from its own mass which spells eventual doom and allow it to live indefinitely? This was actually done some years ago at the Rockefeller Institute for Medical Research. On January 17, 1912, Dr. Alexis Carrel removed a small piece of tissue from the heart of a chick just hatching. He placed this mass of throbbing heart muscle in a solution of chicken blood plasma (the fluid part of blood) and put it in a chamber. The warmth and humidity in the chamber duplicated the conditions in the chicken's body. For some time the heart tissue continued to beat normally. Gradually, however, the beat slowed down and showed evidence of stopping entirely. It appeared that waste products formed in the active tissue were accumulating and would soon poison it. At this point the tissue was washed with salt solutions and beating resumed normally. Regular replacement of plasma removed this problem and the tissue began to grow. As the bulk of the tissue increased, a new problem arose. Tissue deep in the mass could no longer receive nourishment. This problem was corrected by dividing the mass. A routine for care of the tissue culture was

2-8 A piece of the original chicken heart muscle growing in the apparatus developed by Dr. Carrel. (Rockefeller Institute)

established in which new plasma was added and the mass was divided every 48 hours. Is the heart tissue still living after more than 50 years? It could be, had not the experiment ended in the late 1940's. As a part of a normal chicken heart, subject to growth and maturity, it would have died in five to 10 years or less. Thus, we might conclude that organisms have definite life spans, even though their substances have the capacity for indefinite life.

Living things have the capacity to reproduce. Since the life of a plant or animal is limited in duration, reproduction is necessary to perpetuate life. Reproduction takes many forms in the living world. It may be the division of a cell, or the formation of a special cell such as an egg. It may even consist of the removal of a part of a parent organism which is capable of independent growth, such as the cutting of a stem or a root of a plant. The same principle is always involved, however — a mass is divided or a small portion of a mass is separated from the parent. A seed contains a small amount of substance of the parent plants. A human being develops from a mass of living material no larger than a pinhead, contributed by both parents and capable of living and growing a lifetime.

Living things are capable of response. Only living protoplasm has the capability of responding to external conditions. We refer to this interaction of a living system and its environment as ***irritability***. The environmental *stimulus* may be a light factor, temperature, water, sound, pressure, the presence of chemical substances or a source of food, or a threat to survival. The *response*, or reaction of the organism to the stimulus, varies with its capability. This capability is determined by the structural and physiological organization of the organism. For example, a plant response may be a growth reaction, as when a root pushes through the soil toward a water supply, or when a stem grows unevenly and bends toward the light on a window sill.

Animals are capable of reacting in more complex ways or on higher levels. Sight, hearing, taste, touch, and smell are responses to environmental conditions. More complicated responses include fleeing from an enemy, defending oneself in time of danger, hunting for food, and seeking a place in which to build a nest. Nonliving substances may be influenced by environmental conditions, as when water freezes and becomes ice or changes to steam at the boiling point. But these changes in form are not responses. Only living organisms are capable of responding to a stimulus.

Living things have a critical relationship with the environment. All organisms face a constant struggle for life. Part of this struggle centers around requirements for maintaining the living condition. Another part involves a struggle with other forms of life to survive in a highly competitive biological society.

Environmental factors such as light, moisture, oxygen supply, temperature, air currents, soil conditions, and variations in the earth's surface have a direct influence on living organisms. Environmental conditions differ in various localities. As these conditions vary, plant and animal life in the region varies. Desert plants and animals cannot survive in a moist woods. Nor can prairie life survive in marshes. From the arctic wastelands to the tropics and from mountains to valleys, there are certain kinds of organisms that find each environment ideal.

The environment must supply plant life with materials with which to organize the complex chemical substances required as food. Animals in turn eat the plants. Thus, plants become part of the necessary environment of animal life.

Even if the environment is proper, a plant or animal must compete with other living things. Sometimes the struggle is competition for the needs of life. Other times it is a struggle with natural enemies. A small tree growing from the forest floor must compete with many other plants for a place to grow. A few survive, while many perish. The robin is a constant threat to the worm and caterpillar. But hawks, crows, and cats are a constant threat to robins. The struggle for existence is a problem to all living things.

Variation and adaptation. Conditions in an environment change from time to time. Sometimes these changes are sudden, as in the case of a severe drought, a destructive storm, or a devastating fire. Other changes may occur much more slowly and over a long period of time. These include climatic changes, changes in soil, or the gradual erosion of hills and mountains. If an organism is not entirely suited to its environment, it can no longer satisfactorily compete with other living things. One of three things must happen: 1. it must *migrate* to more suitable surroundings; 2. *adaptations* must occur; or 3. it will *perish* as a species.

Animals capable of movement may leave unfavorable surroundings and seek an environment in which they can meet their needs. These migrations may be seasonal or more permanent, depending on the nature of the environmental changes. Plants for the most part lack this motility and must survive or perish in the place where they are growing. However, even the nonmotile plants produce seeds and fruits or other reproductive structures which may be distributed far from the parent plant. If even a few seeds chance to fall in favorable places, the species survives.

Another characteristic that allows organisms to survive changing conditions is ***variation.*** This means that no two offspring are exactly alike, nor are they exactly like their parents. Countless variations occur which do not affect survival. Some are harmful and may even hasten death. Occasionally, however, a variation occurs which gives an organism a better chance to survive. If the plants or animals having these favorable chance variations interbreed, the species may gradually become better suited to its environment. We speak of this process as ***adaptation.***

We shall consider one example of adaptation in the deer family. The white-tailed deer ranges over most of North America, Mexico, and Central America. In the North, it is a slender, long-legged animal. It can run at top speed through a dense forest and hurdle logs five feet or more off the ground. In Florida a tiny deer known as the Key deer lives in the marshes. This "toy" variety of the white-tailed deer weighs 50 pounds or less. It can easily hide in a clump of marsh grass. The Key deer could not survive in the northern forest. Wolves and other flesh-eating animals would have exterminated it years ago. But neither could the northern white-tailed deer find shelter in the marshes of Florida.

In referring to adaptation we often speak of an organism as modifying to fit its environment. This does not happen. Plants and animals do not change *in order* to survive. They survive *because* of change. The northern variety of the white-tailed deer did not develop long legs in order to run fast. It runs fast because it has long legs. This happens to be a favorable variation for the northern deer. Long legs make it better adapted to its total environment by enormously improving its chances for survival.

Thus, whether variations are favorable or unfavorable, we may add the possibility of variation to our list of characteristics of the living condition.

IN CONCLUSION

What, after all, is the living condition? Is it origin by biogenesis? Is it the organization of the complex materials composing protoplasm? Is it cellular organization and cell activity? Is it growth, reproduction, and control by genes? Is it capability of response and a critical relationship with the environment?

The fact is that life is all of these and more. A definition of life is difficult to make. Biologists have compared the problem of defining life with shadow boxing. You strike out with what seems to be a specific property of the living condition only to find that it does not always apply, or that it is only a partial definition. Perhaps we can summarize by saying that life is energy transformations occurring in chemical changes involving the various materials present in a cell.

It is logical, then, that our next approach to the study of life should concern chemistry, from the most basic forms of matter to the complex chemical products of life activities.

BIOLOGICALLY SPEAKING

adaptation
biogenesis
irritability
life span
organism
protoplasm
spontaneous generation
variation

QUESTIONS FOR REVIEW

1. What is the biological concept of an organism?
2. Summarize the meaning of biogenesis.
3. Give examples of myths founded on belief in spontaneous generation.
4. Describe Redi's experiment to disprove spontaneous generation.
5. What evidence in Needham's experiments led him to the false conclusion that microorganisms developed in broth by spontaneous generation?
6. How did Spallanzani refute Needham's conclusion?
7. Describe the flasks Pasteur used in his experiments to disprove spontaneous generation.
8. Give a definition of protoplasm in line with modern biological concepts.
9. In what way is growth by assimilation different from growth of nonliving material?
10. Explain how growth of an organism is regulated internally.
11. List five stages in the life span of an organism.
12. In what respect is the cell the common denominator of life?
13. Define irritability.
14. List several environmental conditions that have a direct influence on living organisms.
15. List three possible consequences of an organism not being suited to its environment.
16. Explain the relationship of variations to adaptations.

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss how Redi's experiments comply with modern scientific practice.
2. Explain how Pasteur accounted for all variable factors in his experiments disproving spontaneous generation of microorganisms.
3. Discuss the biological principles demonstrated in Dr. Alexis Carrel's famous experiment with chick heart tissue.
4. Discuss various ways in which living organisms respond to external stimuli.
5. In what ways is the struggle for existence a problem to all living things?

CHAPTER 3

THE CHEMICAL BASIS OF LIFE

What is matter? We may define *matter*, simply, as *anything which occupies space and has mass.* Or you might think of matter as any form of substance — a liquid, a solid, or a gas. Can you think of any form of matter that would not fit this definition? We ordinarily think of solids and liquids as occupying space and having mass. But what about gases, such as oxygen, nitrogen, hydrogen, and carbon dioxide? Do they occupy space and have mass? Air is a mixture of gases. Does an inflated tire weigh more than a flat tire? If so, air has mass. And what about hydrogen? A hydrogen-filled balloon rises through the air. Does hydrogen weigh even less than air? Light as it is, hydrogen still has mass and therefore has weight.

Matter may be changed from one form to another without altering its chemical composition. Such a change is referred to as a *physical change.* This occurs when water changes from a liquid to ice at the freezing point and to steam at the boiling point. It may also change from a liquid to gaseous water vapor by evaporation. In these changes the chemical structure of the water is not altered.

When a *chemical change* occurs, matter changes chemical composition. A chemical change takes place when wood burns. The substances composing the wood are transformed into various gases which enter the atmosphere and solid materials which remain as ash. Thus, the substances which composed the wood are in new chemical forms as a result of a chemical change. How was the wood formed in the first place? This required many chemical changes which occurred in the cells of a living tree.

Energy and energy changes. ***Energy*** is associated with matter, but it is not a form of matter. We may define it as the *capacity for doing work or causing a change*, or a force which acts on matter or has the potentiality for acting on matter. Notice that energy may be an active force, and that it may also exist with the possibility of release as an active force.

We speak of energy representing capacity but not actively released as *potential energy.* When it is actively expressed, as in motion, we refer to it as *kinetic* (ki-*net*-ik). During an energy change, potential energy may become kinetic. Similarly, kinetic energy may be converted to potential energy. For example, a boulder resting at the

3-1 The potential energy of water at a high level changes to kinetic energy as it falls over the water wheel. (Ewing Galloway)

top of a hill has potential energy because of its position. As it rolls down the hill, this energy becomes kinetic, or energy of motion.

Energy of position is one form of potential energy. *Chemical energy* is another form. You will discover how this energy exists in the organization of chemical compounds and how it may be released and converted to kinetic energy during chemical changes. Kinetic energy may occur as *electric current, heat, visible light,* and invisible radiations including *ultraviolet rays, X rays, gamma rays,* and *cosmic rays.*

Elements, the alphabet of matter. All of the words of our language are formed from 26 letters in various combinations. When you think of the size of an unabridged dictionary, you realize what an enormous number of combinations these letters can form. In somewhat the same way all matter in the world is composed of 92 natural, basic substances called ***elements,*** in various chemical combinations. In addition to these 92 natural elements, 11 more have been produced in atomic research laboratories. Thus the total number of known elements at the present time is 103. Only about 30 elements, however, are well known, and less than half this number form more than 99 percent of the substances of the earth and atmosphere. We might think of the natural elements as a 92-letter chemical alphabet with most of the words formed from no more than 30 of these letters.

Elements are composed of extremely small units of matter called ***atoms.*** Even the largest atoms are less than one 50-millionth of an inch in diameter. The smallest atoms, those of hydrogen, have been estimated to be less than one 250-millionth of an inch in diameter. When we say that atoms are basic units of matter, we mean that *in ordinary chemical reactions,* a substance is reduced no further than its individual atoms. Similarly, you can reduce a word to its letters, but you cannot split its letters.

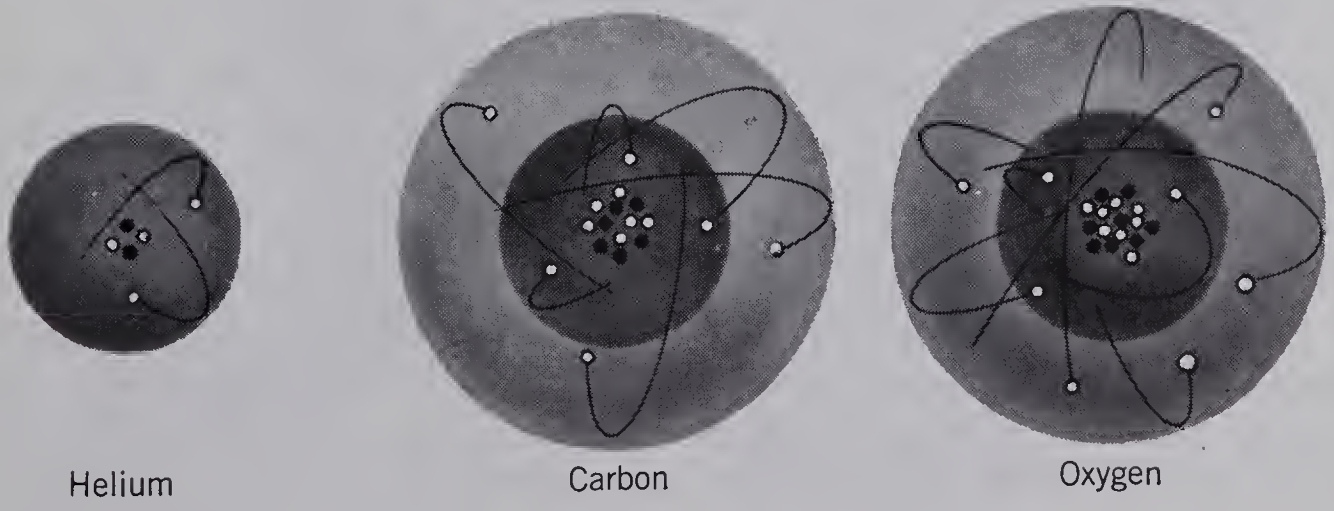
We designate one atom of an element by means of a *symbol.* The symbol is the first letter or first two letters of the name of the element. For example, C stands for one atom of carbon. H represents one atom of hydrogen, while O is one atom of oxygen. Some chemical symbols refer to the Latin name of an element which is no longer used. For example, Na is sodium, Fe is iron, and Ag is silver. Chemical symbols are used in referring to elements and to the substances formed from combinations of elements. They are the chemist's shorthand.

The structure of an atom. Can you think of anything smaller than the smallest atom? You probably can because you live in an age in which we speak of atomic particles. But this has not always been true. For centuries even the best informed chemists thought that atoms were indivisible forms of matter — the smallest particles that could exist. Today, however, we know that atoms are composed of still smaller particles. These same particles make up all atoms. The difference between oxygen, hydrogen, sulfur, iron, gold, uranium, and all other elements is not the kind of particles composing their atoms but the number and arrangement of these particles.

An atom is composed of two and, in most cases, three basic particles. The central mass of an atom is referred to as its ***nucleus.*** The nucleus contains one or more particles with positive electrical charges which we refer to as ***protons.*** Varying numbers of ***neutrons*** are also present in the nucleus. These particles weigh about the same as protons, but have no electric charges. The ***atomic mass*** of an element is the sum of its protons and neutrons. The ***atomic number*** refers to the number of protons in the nucleus of that atom, regardless of the number of neutrons present. No two elements have the same number of protons.

Extremely small, relatively weightless particles move around the nucleus at a high rate of speed. These are ***electrons.*** Each electron bears a negative charge. With certain exceptions, an atom has the same number of electrons as protons. Thus, the negative electron charges balance the positive proton charges in the nucleus. Such an atom is electrically neutral.

Hydrogen to uranium — the series of natural elements. If you had a pile of protons and a pile of electrons and started to construct 92 elements from these particles, where would you begin? Wouldn't you start with one proton and one electron? This is the structure of a hydrogen atom, with the atomic number 1. Add another proton and a second electron and you have an atom with the atomic number 2. This is helium. Lithium has the atomic number 3. As atomic numbers are increased, different elements are produced. At the end of this series of natural elements is uranium, with 92 protons and therefore the atomic number 92.

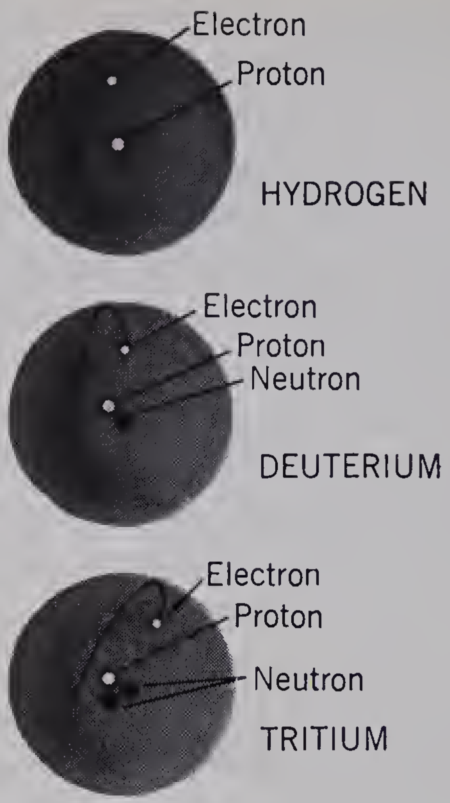


3-2 Diagrammatic representations of atoms. Protons are shown as white circles; neutrons as black circles. Electron orbits are shown as streaks around the nucleus.

Now we must consider atomic masses — the sum of the protons and neutrons. For example, oxygen has the atomic number 8, but an atomic mass of 16 in most cases. How many neutrons are there in an oxygen atom? Similarly, carbon atoms have the atomic number 6, and most have an atomic mass of 12. What does this indicate? Most atoms of uranium, with the atomic number 92, have an atomic mass of 238. How many neutrons are present?

What are isotopes? The atomic number of an element never varies. In other words, the number of protons is constant. However, the number of neutrons may vary in different atoms of the same element. This variation in neutrons results in differences in the atomic masses of atoms. Such different forms of an element are referred to as ***isotopes.*** Various isotopes may exist naturally, or they may be produced artificially.

Hydrogen is an example of an element with three isotopes. Ordinary hydrogen has a single proton and therefore an atomic mass of 1. However, another hydrogen isotope, known as deuterium, has a proton and a neutron composing its nucleus and thus weighs twice as much as ordinary hydrogen. A third isotope of hydrogen, known as tritium, has been produced artificially. This isotope has a proton and two neutrons, giving it three times the weight of ordinary hydrogen. The atomic weight of hydrogen is actually not 1 but 1.0079. In other words, we determine the atomic weight by averaging the weight of all of the natural isotopes of an element. The actual atomic weight of hydrogen shows you that very few atoms in a mixture of natural hydrogen isotopes are deuterium, the heavier form of the element. All atomic weights today are based on a comparison of the most common isotope of carbon, with a mass of exactly 12. The common hydrogen atom has one-twelfth the mass of the common carbon atom, and thus is said to have a mass of one.



3-3 Diagrams representing the isotopes of hydrogen.

Many other elements have isotopes, some natural and some artificial. Oxygen has three natural isotopes and three that have been formed artificially. The same is true of carbon. There are four natural isotopes of iron and four artificial forms. Iodine has a single natural isotope, but 17 other isotopes of iodine have been produced artificially.

Several natural elements have unstable nuclei that undergo gradual disintegration and emit radiations. These unstable isotopes are classed as *radioactive.* Elements with naturally occurring radioactive isotopes are uranium, radium, and thorium. Their radiations may be alpha particles, which are helium nuclei (two protons and two neutrons) traveling at a speed of 10,000 to 20,000 miles per second. Beta particles are electrons which travel at a speed of

60,000 to 160,000 miles per second. Gamma rays, another form of radiation, are high-energy X rays. These are the most penetrating radiations emitted from the nuclei of radioactive elements.

In addition to the natural radioactive elements, many other elements have radioactive isotopes which have been produced artificially. Among these are oxygen, calcium, cobalt, and strontium. These radioactive isotopes are produced by bombarding atomic nuclei with neutron "bullets" in atomic reactors. Radioactive materials are very important in scientific research as tracer elements which can be identified in chemical reactions. Others, including radioactive phosphorus, cobalt, and iodine have important medical uses both in the diagnosis and in the treatment of various diseases.

The combining properties of elements. The particles in the nucleus determine the mass of an atom. The number and arrangement of electrons determine its chemical activity. As the number of protons in the nucleus increases, so does the number of electrons speeding around this central mass. Do electrons orbit around the nucleus in definite patterns, or do they travel in erratic paths? Scientists are not sure. Some have referred to an electron cloud or haze around the nucleus. Others have likened moving electrons to bees swarming around a hive. However, even if

3-4 The Geiger counter shown is being applied to the thyroid gland of a patient who has been fed radioactive iodine. The areas of concentration of iodine are recorded at the right. (Oak Ridge Operations Office) electron paths are erratic and indefinite, there is some order in their arrangement, or *configuration.*

Electrons move at different distances from the nucleus of an atom. The greater the distance, the higher the energy level. These energy levels are also referred to as *shells.* Furthermore, chemists have found evidence that various shells can accommodate only limited numbers of electrons. The first energy level, or K shell, lies nearest to the nucleus. This shell can hold but 2 electrons. The second energy level, or L shell, may contain 8 electrons. The third energy level, or M shell, also usually holds 8 electrons. Beyond the third level, the electron configuration of atoms becomes more and more complex. Energy levels continue to a seventh shell.

The chemical activity of an atom is determined by the number of electrons in its highest energy level, or outer shell. If the shell is filled, the atom is said to be stable and has little or no chemical activity. For example, helium has only 2 electrons. These fill the K shell. Helium is therefore a stable element. The next stable number is 10 (2 electrons in the K shell and 8 in the L shell). The element with this atomic number is neon, another stable element. The third energy level is filled with 8 electrons when the atomic number 18 is reached (2 in the K shell, 8 in the L shell, and 8 in the M shell). Argon, another stable element, has this atomic number.

However, most atoms have electrons missing in their outer shell. This produces chemical activity, since an atom tends to become more stable by filling its outer electron shell. This chemical activity will result in one of two things:

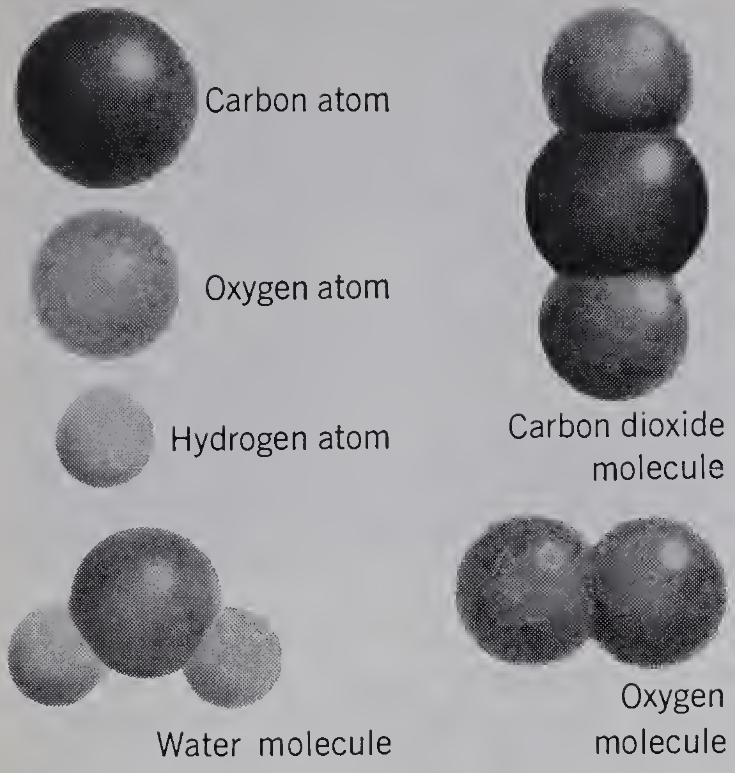
1. Atoms may *share* electrons with other atoms, or
2. Atoms may *transfer* electrons from one atom to another.

Whether an atom is an electron sharer or an electron borrower or lender determines the nature of the substance the combined elements will produce.

The nature of covalent bonds. When atoms join and fill their outer shells by sharing pairs of electrons, they reach a more stable state. The force which holds the atoms together is known as a *bond.* When the force results from the *sharing* of pairs of electrons, it is known as a ***covalent bond.***

Certain atoms, including gases such as hydrogen, oxygen, nitrogen, chlorine, and others share a pair or pairs of electrons with each other. This produces a molecule of a single element. A ***molecule*** is the smallest portion of a substance that keeps the properties shown by the substance in large quantity. Thus these gases do not retain their properties when they are in the form of single atoms, but only when they are in combinations of two. We refer to such combinations as *diatomic molecules* and designate them as H_2, O_2, N_2, or Cl_2.

Unlike atoms also form molecules by covalent bonding. Water is a good example. Oxygen, with the atomic number 8, has two electrons missing in its L shell. It therefore has a tendency to gain two electrons to complete this shell. Hydrogen, you will recall, has a single electron. Thus, an oxygen atom may share electrons with two hydrogen atoms and produce a molecule of water. This molecule is a unit of a ***compound.*** Unlike elements are bonded together and the elements lose their properties. Water is unlike either hydrogen or oxygen.



3-5 Diagrammatic representations of molecules of oxygen, carbon dioxide, and water.

The chemical shorthand for a compound is called a *formula.* As you probably know, H_2O is the formula for water. The water molecule may also be written as H—O—H, using dashes to indicate covalent bonds. This method of shorthand is often preferred by chemists, as it shows the actual arrangement of elements in the compound.

The formation of ionic bonds. We need look no further than table salt — sodium chloride — for an example of the transfer of electrons from one atom to another. In this compound, sodium is an electron lender and chlorine is the electron borrower. Now, let's examine this matter of electron transfer more closely. A sodium atom is normally balanced electrically. The number of electrons is the same as the number of protons. This is also true of a chlorine atom. If a sodium atom transfers one electron, it loses a negative charge. This loss results in an electrically unbalanced atom with a positive charge. Similarly, the addition of an electron to a chlorine atom gives it a negative charge. We refer to these charged atoms as ***ions.*** The opposite electrical charges of the two ions lock them together with a force we refer to as an ***ionic bond.*** The resulting ionic compound is sodium chloride. Many other compounds are formed by ionic bonding. In all of them the electron transfer resulting in the compound involves a metal and a nonmetal. The units of these compounds are not molecules, as in covalent bonding, but are referred to as *ion pairs.*

Properties of compounds. Relatively few elements are found free in nature. Chemical reactions have bonded most of their atoms with other atoms to form compounds, either molecular or ionic.

Compounds are products of chemical changes which are accompanied by energy changes. We will use carbon dioxide as an example of a common molecular compound and show how it is formed by covalent bonding. As an illustration we will use the familiar charcoal grill. To start the chemical reaction it is necessary to light the charcoal. Once the charcoal is lighted it will glow for hours and continue giving off energy as heat and light. The chemist would show the change that occurs by the following equation:

$$C + O_2 \rightarrow CO_2$$

In a *chemical equation* the substances on the left of the arrow, the *reactants,* are undergoing chemical change. In the equation above the reactants are carbon, C (the charcoal) and oxygen, O_2. What was the source of the oxygen that entered into the reaction? How could you prove this? The substances on the right of the arrow, the *products,* are the result of the chemical change. Notice that none of the atoms of the reactants are lost during the change. All are present in some form in the products. Since carbon dioxide is a colorless and odorless gas, you are probably not aware that it is being formed when charcoal burns. This simple chemical change illustrates still another characteristic of the formation of a molecule by covalent bonding — energy is usually given off, as it was in this reaction.

Now to return to the carbon dioxide that escaped unnoticed from the charcoal fire. It was unnoticed because it is a colorless, odorless, tasteless gas. Furthermore, it is heavier than air, which indicates that it probably settled to the ground. Its molecules contain carbon, but do they resemble carbon in any way? They also contain oxygen, but the only resemblance between carbon dioxide and oxygen is the fact that both are colorless, odorless, tasteless gases. In other words, both carbon and oxygen atoms lost their identity in a molecule of carbon dioxide. Each compound has its own physical and chemical properties.

If you examine the formula for carbon dioxide, you will find still another property of a compound. A molecule of carbon dioxide is formed *only* by the chemical bonding of two oxygen atoms and one carbon atom. Suppose a single oxygen atom is joined to a carbon atom. This produces the deadly gas carbon monoxide, with the chemical formula CO. The properties of this compound are quite different from those of carbon dioxide.

How would you separate the atoms in a molecule of carbon dioxide? This would require a chemical change, just as the formation of the molecule requires a chemical change.

We can summarize the properties of a compound as follows:

1. The elements forming a compound are joined by chemical bonds, either covalent or ionic.
2. A chemical change is necessary to separate the elements combined in a compound.
3. The elements forming a compound combine in definite proportions.
4. A compound has its own physical and chemical properties which are different from those of its constituents.
5. The formation and decomposition of a compound involve energy changes.

Properties of mixtures. Elements or elements and compounds may be associated in a ***mixture***, with characteristics quite different from those of a compound. No chemical change is involved in forming a mixture. No bonding of atoms occurs. No new molecular or ionic substance results. We can best describe a mixture by comparing its properties with those of a compound, as follows:

1. The substances forming a mixture are associated physically or mechanically, rather than chemically.
2. The substances in a mixture can be separated by physical means.
3. The proportions of substances in a mixture are variable rather than definite.
4. The mixture has the properties of the various substances forming it.
5. Energy changes are not involved in a chemical action in forming a mixture.

Air is a mixture of gases. The following gases compose air at sea level in these approximate percentages by volume: nitrogen, 78 percent; oxygen, 21 percent; rare gases including argon, helium, neon, krypton, and xenon, 0.94 percent; carbon dioxide, 0.04 percent. Water vapor is also present in air and

3-6 Crystals of sodium chloride, common table salt. When the crystal dissolves, the resulting solution contains dissociated sodium ions and chloride ions. (Bell Telephone Laboratories)

varies from a small amount to 2 percent or more.

If air were not a mixture of gases, there would be no life on the earth as we know it. We breathe air into our lungs, dissolve part of the oxygen into the blood, and exhale the nitrogen and other gases. Aquatic animals absorb oxygen dissolved in water. They cannot make use of the oxygen combined with hydrogen that forms the water itself.

Solutions and suspensions. When a mixture of two or more substances is homogeneous, we refer to it as a ***solution.*** The dissolving medium of a solution is the *solvent.* The dissolved substance is the *solute.* A solution is formed when molecules or ions of a solute are evenly dispersed through molecules of a solvent.

When you add sugar to water, the crystals of sugar dissolve in the water. Molecules of sugar are dispersed evenly among the molecules of water. You can hasten this process by stirring. In this solution, water is the solvent and sugar is the solute. Sugar water may contain varying amounts of sugar. When a given volume of water is holding all the sugar it can and sugar is settling out, we say the solution is *saturated.* Molecular solutions may involve liquids and gases, two liquids, or a liquid and a solid, as in the example of sugar and water. In all solutions, solute molecules are evenly dispersed through solvent molecules.

Ionic compounds such as sodium chloride are generally very soluble in water. The ion pairs separate, leaving the rigid crystal structure, and spread at random throughout the solution. This process is called *dissociation.* It may be represented by the following equation:

$$\overset{+}{\mathrm{Na}}\overset{-}{\mathrm{Cl}} \rightarrow \mathrm{Na}^{+} + \mathrm{Cl}^{-}$$

Ionic solutions such as sodium chloride and water conduct electricity. We refer to them as *electrolytes.* Molecular solutions such as sugar water are *nonelectrolytes.*

Ions of various compounds are very important in the chemical activities of living organisms. They are present in cells, in the body fluids of animals, and in the solutions present in plants. Ions are involved in absorption, in the transmission of nerve impulses, in muscle contraction, and in a great many body activities which we shall discuss later.

The most common ions in organisms include sodium ions (Na^+), chloride ions (Cl^-), calcium ions (Ca^{++}), potassium ions (K^+), hydrogen ions (H^+), hydroxide ions (OH^-), magnesium ions (Mg^{++}), sulfate ions ($SO_4^{=}$), phosphate ions ($PO_4^{\equiv}$), nitrate ions (NO_3^-), carbonate ions ($CO_3^{=}$), and bicarbonate ions (HCO_3^-).

A substance composed of particles that are larger than ions or molecules may form a mixture we refer to as a ***suspension.*** We can form a suspension by stirring starch in water. The particles may remain dispersed through the water for a time, but will eventually settle to the bottom. They do this because the force of gravity is greater than the force that holds them in suspension. Thus, the size of the dispersed particles determines whether a substance will be dissolved in a solution or suspended. Generally speaking, particles large enough to form suspensions can be seen with an optical microscope.

Many substances are composed of particles that are between the size of small molecules which form solutions and large particles which settle out in suspensions. These may be very large molecules or groups of smaller molecules. These substances mix with water in *colloidal suspensions.* In describing **colloids** (*kahl*-oids) we speak of *dispersed particles* rather than solute and *dispersing medium* rather than solvent. However, particles in a colloid remain suspended as do molecules or ions in a solution.

Protoplasm — a colloidal system. In protoplasm large molecules or groups of molecules are dispersed in water, forming a colloidal suspension. The dispersed molecules have an interesting relationship to water molecules in colloidal protoplasm. Without the water content changing, a colloid may change from a fluid, or *sol,* to a semisolid, or *gel.* In the sol phase the dispersed molecules are distributed uniformly through the water molecules. The gel phase results when the dispersed molecules join and produce a spongy network. This physical change traps the water in pools in the molecular net and changes the colloid from a sol to a gel. When the molecules separate and return to a dispersed state, the colloid changes from a gel to a sol. We refer to such a change from sol to gel or gel to sol as a *phase reversal.* This reversal is a common occurrence in protoplasm.

External conditions such as temperature may cause phase reversals in colloids. Gelatin, for example, forms a gel when it is cool, but changes to a sol when it is heated. As the temperature is lowered after heating, it changes back to the gel state. Gelatin is an example of a *reversible colloid.* On the other hand, egg albumen, which is a sol at room temperature, changes to a semisolid when it is heated. A fried egg cannot be changed back to a sol by cooling it. Egg albumen is thus an *irreversible colloid.*

Elements, compounds, and organisms. Earlier in this chapter, we referred to the 92 natural elements which compose

ELEMENTS ESSENTIAL TO MAN

Element	*Amount in Body (154-pound man)*
Zinc Copper Fluorine Silicon	Minute Traces
Iodine	.00006 lb.
Manganese	.0045 lb.
Iron	.006 lb.
Magnesium	.077 lb.
Chlorine	.23 lb.
Sodium	.23 lb.
Sulfur	.35 lb.
Potassium	.54 lb.
Phosphorus	1.54 lb.
Calcium	2.31 lb.
Nitrogen	4.62 lb.
Hydrogen	15.4 lb.
Carbon	27.72 lb.
Oxygen	100.1 lb.

all of the substances of the earth. Now that we are ready to limit our discussion of chemistry to biology, we can cut this number of elements to about 18. These are the elements most common in compounds which form living organisms and supply the substances necessary for their vital chemical activities. Eighteen elements present in the body of a 154-pound man are listed in the table on page 42.

With certain variations these elements might be listed for any organisms. Notice that those present in quantity are among the most abundant elements of the earth. How would the life of our earth be altered if certain of the rare elements were necessary to produce an organism or maintain its existence?

With the exception of atmospheric oxygen, used by most organisms in respiration, all of these essential elements come from compounds present in the soil and atmosphere. We class these compounds as ***inorganic*** to distinguish them from the more complex organic products of the chemical processes of living organisms.

Water is an inorganic compound so important to organisms that it is a primary factor in determining where living things can survive. We will refer to water relations in many phases of our study of biology.

We can summarize some of the ways in which living organisms depend on water as follows:

1. Water is the chemical source of hydrogen and provides some of the necessary oxygen.
2. It is the medium in which materials are dispersed in the organization of protoplasm.
3. It is the medium in which soluble materials are absorbed from the environment.
4. It is the medium of transport of foods, minerals, and other vital substances in living systems.
5. Water provides the environment for aquatic organisms.
6. Water pressure in plant tissues provides the firmness that supports the plant.

Carbon dioxide is an inorganic compound that is the source of carbon as well as oxygen. Carbon is a key element in the organization of all organic compounds. Thus, we can say that carbon dioxide is, directly or indirectly, essential for life.

The other essential elements come from *mineral compounds.* These may be in the form of soil minerals, minerals dissolved in water, or salts present in sea water.

Perhaps it has occurred to you that we, as living organisms, do not directly utilize carbon dioxide and many of the essential minerals. We could not produce our bodies from water, carbon dioxide, and minerals. There must be a link between inorganic compounds and the organic substances we require as foods. The green plants of the earth provide this vital chemical link. You will deal with many phases of this biochemical relationship in your study of biology.

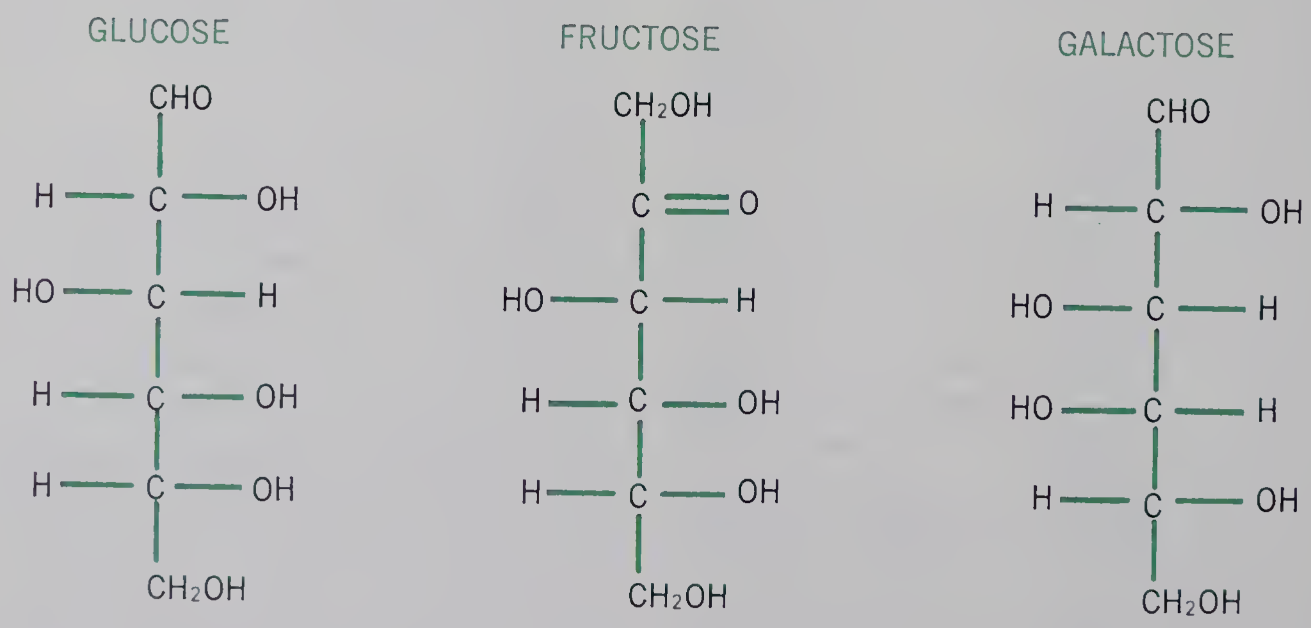
Carbon – the key to organic compounds. We might divide all compounds into two basic chemical groups – inorganic and organic compounds. All of the ***organic*** compounds are carbon compounds. At one time, chemists thought that all organic compounds were products of the chemical processes of organisms. This accounts for the name *organic.* Today, however, we know that this is not the case. In fact, many of the organic compounds we use today are synthetic products of chemical industries. However, we *can* say that all organic molecules are formed around carbon atoms. Organic chemistry might thus be spoken of more accurately as carbon chemistry.

Carbon has several chemical properties which make it the key element in organic compounds. One is the nature of its atomic structure. A carbon atom has four electrons in its outer shell, which is the L shell. Since a completed L shell consists of 8 electrons, carbon atoms tend to complete their outer shells by sharing their 4 available electrons with those of other atoms. Carbon atoms thus link together by covalent bonds in chains or rings. These carbon groups form the framework to which atoms of other elements attach to form large and complex molecules. This property of carbon makes possible the formation of an enormous number of organic molecules. The structural formulas of several organic molecules are shown in Fig. 3–7. Notice that the carbon atoms form chains in some of the molecules and rings in others. The covalent bonds are shown as lines joining atoms. When the carbon atoms share two electrons instead of one, a *double bond*, shown by two lines, is formed. A *triple bond*, shown by three lines, is formed when the carbon atoms share three electrons. Notice that each carbon atom has a total of four single bonds linking it to another carbon atom or to an atom of another element.

The organization of organic molecules by living organisms is known as ***biosynthesis***. Just how the build-up of atoms and smaller molecules to the intricate pattern of organic molecules occurs is a matter of great interest to biochemists today. Somewhere in this maze of cell chemistry must lie the key to life. We shall continue this search in the exploration of organic compounds.

The nature of carbohydrates. A ***carbohydrate*** is an organic compound containing carbon, hydrogen, and oxygen. The hydrogen and oxygen are present in a ratio of 2:1, as in water (H_2O).

Sugars are the most abundant carbohydrates. While they all contain the same elements, the number and arrange-



3-7 Structural formulas of molecules of three simple sugars. Note that all three have the same number of carbon, hydrogen, and oxygen atoms. Their properties are different because of the arrangement of atoms in the molecule.

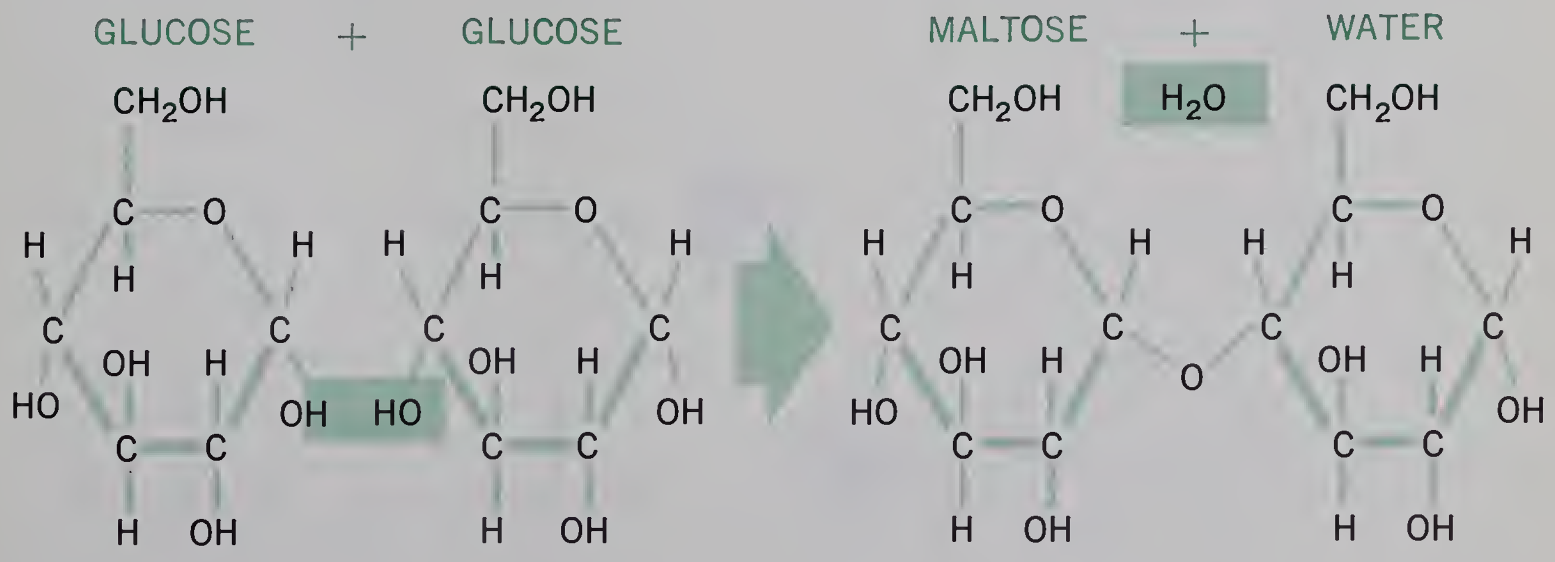
ment of atoms in sugar molecules produces a great many different compounds. Many sugar molecules are constructed around a chain of six carbon atoms (Fig. 3–7). These six-carbon sugars, known as simple sugars, or *monosaccharides* (mon-oh-*sak*-uh-ryds), have the chemical formula $C_6H_{12}O_6$. Variations in the arrangement of these atoms results in several different sugars with the same chemical formula. *Glucose* is a most important sugar in organisms. It is abundant in plants as well as in animals. We also refer to it as dextrose and blood sugar. *Fructose,* or fruit sugar, and *galactose* are other monosaccharides.

Certain plants combine two six-carbon sugar molecules, remove one molecule of water, and form a more complex double sugar, or *disaccharide* (dy-*sak*-uh-ryd). These sugars have the formula $C_{12}H_{22}O_{11}$. Two glucose molecules are joined in *maltose,* or malt sugar (Fig. 3–8). A molecule of glucose may combine with a molecule of fructose to form *sucrose,* or cane sugar. This is our common table sugar, produced by the sugar cane and the sugar beet. A molecule of glucose joined to a molecule of galactose produces *lactose,* or milk sugar.

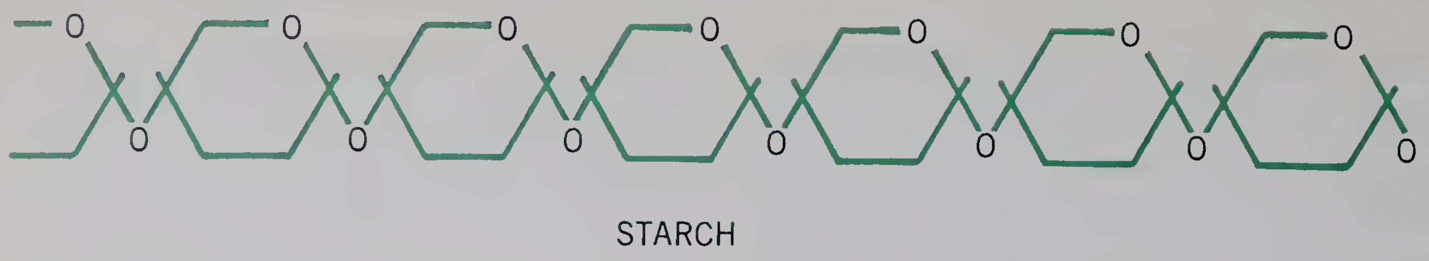
The *starches* are complex carbohydrates composed of glucose units in chains (Fig. 3–9). They are classed as *polysaccharides.* Each glucose unit in a polysaccharide consists of a six-carbon sugar molecule from which a molecule of water has been removed. The chemical formula for a polysaccharide is frequently shown as $(C_6H_{10}O_5)n$. The letter n indicates a chain of the basic saccharide units.

Glycogen (*gly*-ko-jen) is a polysaccharide composed of 12 to 18 glucose units in a chain. It is produced in the liver as a carbohydrate storage product. When the need arises, the liver reconverts glycogen to glucose by adding a molecule of water to each unit. The glucose is then delivered to the tissues as blood sugar.

Starches such as corn starch and potato starch are even more complex polysaccharides. These molecules are composed of a chain of 24 to 26 glucose units. *Cellulose* molecules consist of as many as 2,000 glucose units. This complex carbohydrate is formed in plant cells and deposited in cell walls. You



3-8 Two glucose molecules combine to form one molecule of maltose, splitting off one molecule of water in the process. Here glucose molecules are shown as ring structures rather than chains, as in Fig. 3-7.



3-9 A diagram showing how many simple sugar molecules may combine in a starch molecule. Only a small part of the starch molecule is represented.

are familiar with cellulose as paper, wood, cotton, hemp, linen, and other common substances.

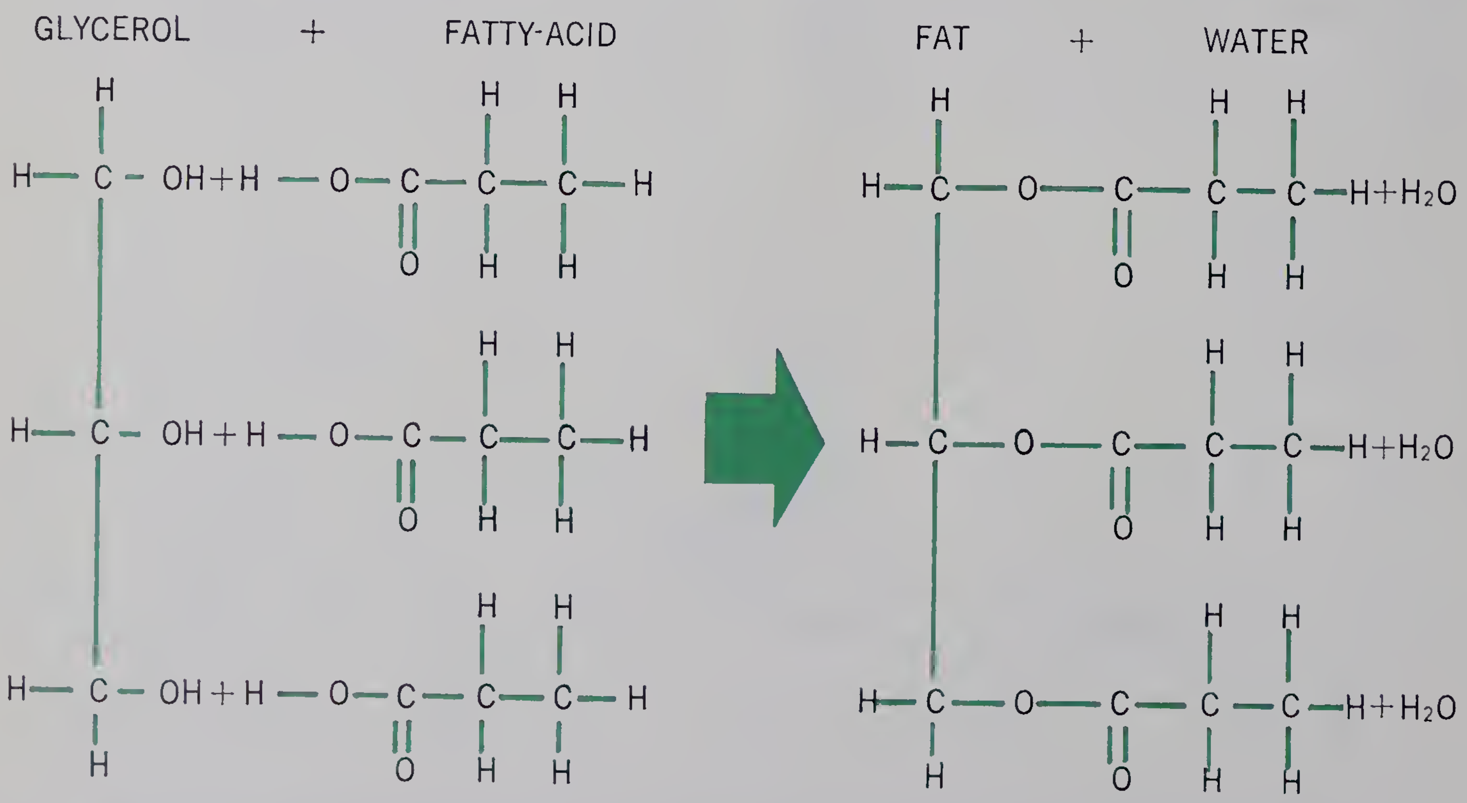
For the most part carbohydrates are the energy sources in living organisms. Not only in plants, which organize them, but also in animals, which consume them, carbohydrates are vital fuel nutrients.

Fats, oils, and related substances. ***Fats,*** including oils and waxes, make up a second class of organic compounds. They are composed of carbon, hydrogen, and oxygen and in this respect are similar to carbohydrates.

Fat molecules are built up from combinations of simpler units known as *glycerol* (glycerin) and *fatty acids.* Glycerol molecules contain a chain of three carbon atoms and have the formula $C_3H_8O_3$. Fatty acids vary in chemical make-up and contain a chain of from two to more than 20 carbon atoms. In forming fats three fatty acid molecules are joined to one glycerol molecule (Fig. 3–10). Three water molecules are formed as a by-product.

During fat digestion, water is combined with fat molecules and the fat is broken down to fatty acids and glycerol. We refer to this process as ***hydrolysis.***

The conversion of vegetable oils to animal fats is an interesting process. These oils, liquid at room temperature, have double bonds joining some of their carbon atoms. Chemists refer to them



3-10 A molecule of glycerol combines with three fatty acid molecules to form a fat molecule, splitting off three molecules of water.

as *unsaturated* because their molecules are not holding all of the hydrogen atoms of which they are capable. When one of each of these double carbon bonds is taken over by a hydrogen atom, the molecule is changed to one of a fat which is solid at room temperatures. Such fats are spoken of as *saturated.* The process in which they are formed is *hydrogenation.*

Waxes are related to fats but are more complex. Other relatives of fats and oils are the *sterols,* including *ergosterol* (er-*gahs*-ter-ol), a substance in foods and in the skin from which vitamin D is produced, and *cholesterol,* a fatty material that forms in the body.

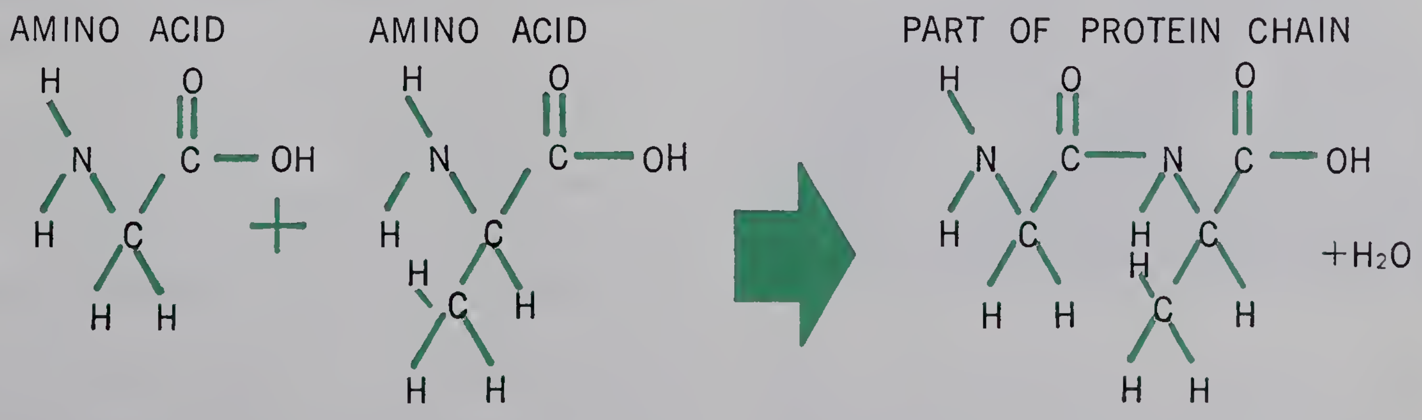
Proteins and amino acids. The most abundant chemical compounds in living cells are ***proteins.*** They are also the most complex and variable. Protein molecules contain carbon, hydrogen, oxygen, and nitrogen. Sulfur is often present and phosphorus and iron may be included.

Protein molecules consist of complex groups of smaller units known as *amino acids.* All amino acids are alike in containing an *amino group* and a *carboxyl group.* The amino group consists of two hydrogen atoms bonded to a nitrogen atom (NH_2), while the carboxyl group contains an atom of carbon, two atoms of oxygen, and a hydrogen atom (COOH). More than 20 different amino acids are formed from these two groups bonded with other atoms and groups of atoms (Fig. 3–11).

Amino acids are arranged in one or more chains in forming a protein molecule. The number of amino acids in a protein chain may be from 300 to 3,000. When you consider that there are more than 20 different amino acids and that proteins differ not only in the kind of amino acids present but in their number and arrangement in chains, you can see that the number of different kinds of proteins is almost endless.

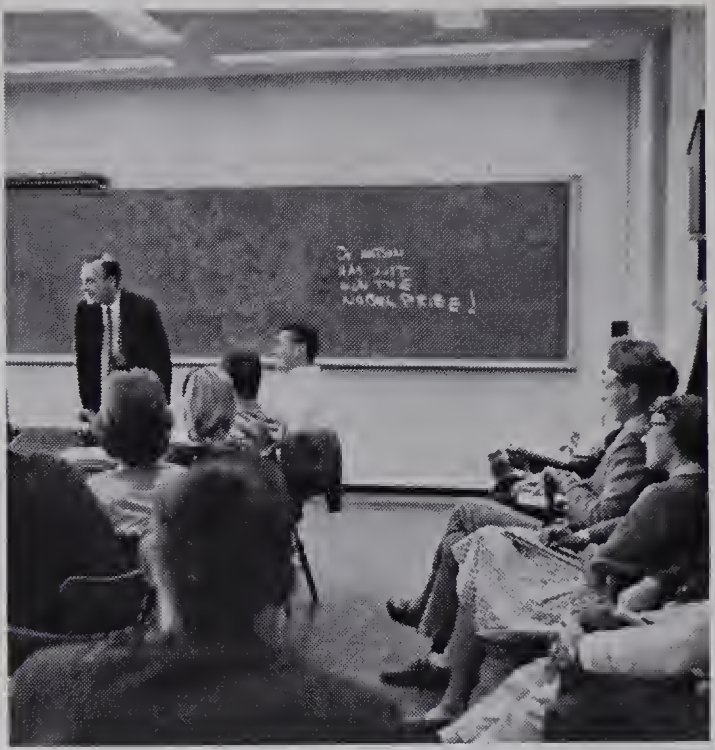
The protein content of different kinds of plants and animals varies greatly. Members of a species have many kinds of proteins in common. For example, certain kinds of proteins are found in all humans, and they are different from those of other animals or of plants. However, while we are like all other humans in certain parts of our protein make-up, each of us has his own individual protein make-up. Each of our cells is said to contain as many as 2,000 different kinds of protein. Could it be, then, that certain proteins make us human while others make us individuals? This is exactly the case, and later you will discover how these proteins are organized and why they make you a human and an individual human.

When we consume plant and animal proteins as food, we take in sub-



3-11 Proteins are composed of amino acids linked up in various combinations. Amino acids contain nitrogen, N, as well as hydrogen, oxygen, and carbon.

stances that are foreign to our make-up. In other words the proteins we consume could not be organized into our own substance. However, during digestion we break them down to amino acids. Later, we rearrange the amino acids and form new protein chains according to our own individual formulas. Altogether, about 20 different amino acids are found in our cells. Foods containing all of the amino acids composing our own proteins are said to be *complete.* As you might expect, these are animal proteins. On the other hand, certain amino acids may be lacking in plant proteins. For this reason they are classed as *incomplete* proteins.



3-13 Dr. Watson shown holding a regular biology class for Harvard and Radcliffe students the day he was told of receiving the Nobel prize. (Wide World Photos)

The vital role of enzymes. So far we have discussed various organic materials which compose living matter. They are the products of the chemical activity of organisms. The chemical phases of the living condition involve literally thousands of changes in which molecules react with other molecules. A living cell is thus a complex chemical system, constantly building up substances and tearing them down.

However, the many chemical activities involved in the living condition could not occur without *enzyme* action. An enzyme is an *organic catalyst.* A catalyst enables a chemical reaction to occur which would otherwise occur too slowly or not at all. The catalyst is not changed during the reaction and does not enter into the products formed. For this reason, they are not used up in a chemical change. Without enzymes as catalysts, you could not digest a meal, release energy in your body, or form your own body substances. In fact, without enzymes there would be no life.

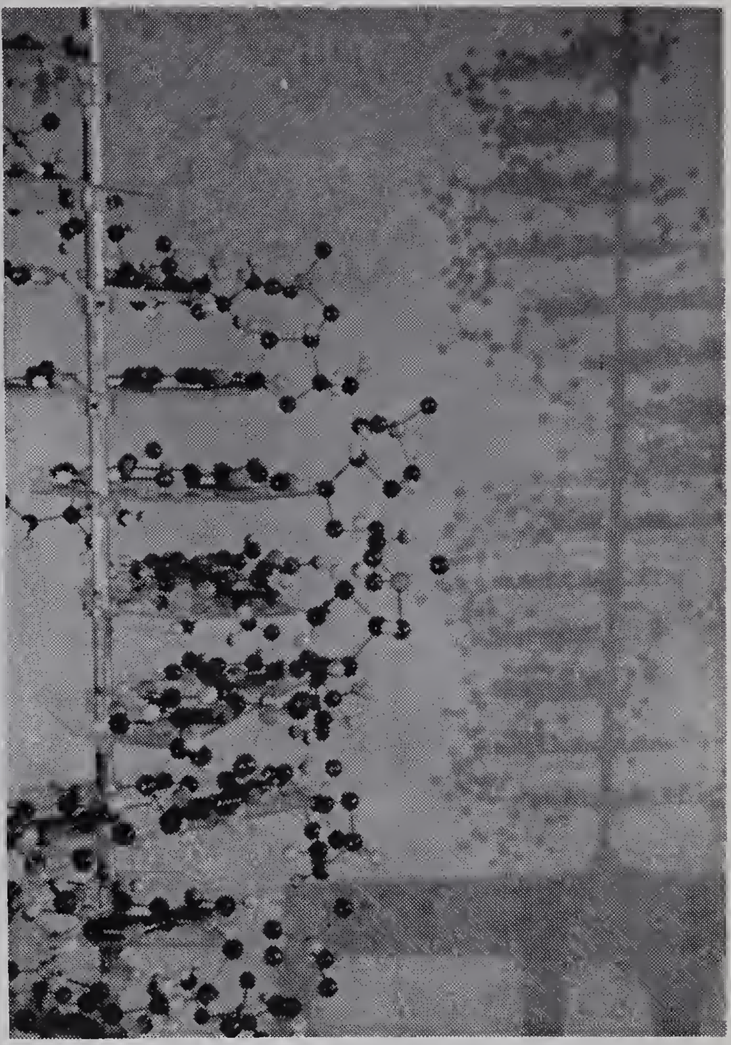
All enzymes are protein molecules. The number of enzymes present in a cell may be as many as several thousand. Each kind of enzyme has an effect only on a certain kind of molecule. In this respect enzymes are *specific.* Thus, for every chemical activity of an organism, there is a corresponding enzyme. Often

3-12 Francis H. C. Crick (above) and James D. Watson were awarded the Nobel prize in 1962 for their workable model of one of the nucleic acids, DNA. (Wide World Photos) a series of chemical changes is involved in a chemical activity of a cell. This requires a group of enzymes we refer to as an *enzyme system*.

In certain chemical reactions enzymes require the assistance of nonprotein molecules known as ***coenzymes***. Coenzymes serve as electron donors or acceptors in chemical reactions. Certain chemical reactions which we shall study later involve the removal or addition of hydrogen atoms from molecules. In these reactions a coenzyme teams with an enzyme in causing the reaction. A coenzyme acceptor receives the hydrogen as it is released, while a coenzyme donor supplies the hydrogen as it is needed.

The organization of nucleic acids. Life is self-perpetuating. Living things have a unique chemical organization. Living things are capable of growth. Living things have a definite form and size range. Do you remember these characteristics of the living condition we discussed in Chapter 2? We presented them merely as interesting observations. But what factor or property of living material accounts for them? This was a puzzle to the biologist until a few years ago when two scientists made a discovery which is among the most significant biological advances of all time. What had been isolated pieces of a puzzle suddenly formed a revealing and thrilling picture of life when the missing piece was finally supplied.

For many years biologists had looked to the cell nucleus as the center of control of all of its activities. Furthermore, they were familiar with the dark, rod-shaped bodies known as chromosomes, which are contained in the nucleus. Other studies prior to World War II had established that chromosomes contain two substances, *protein* and *nucleic acid*. The question was whether the control of cell activity centered in the protein or in the nucleic acid. Studies at the Rockefeller Institute during World War II provided evidence that nucleic acid and not protein controlled all chemical activities of an organism. What were these nucleic acid molecules which possessed such remarkable properties? Their chemical composition was known, but their physical structure — the way their atoms are actually arranged — was not.



3-14 A portion of the DNA molecule as conceived by Watson and Crick. (Sloan-Kettering Cancer Center)

In 1953 two young scientists working in the Cavendish Laboratory at Cambridge University made a startling discovery. One member of this remarkable team is an American biologist, James D. Watson. The other is a British biophysicist, F. H. C. Crick. Together they worked out the physical structure of probably the most complex of all organic molecules, deoxyribonucleic acid, or *DNA*.

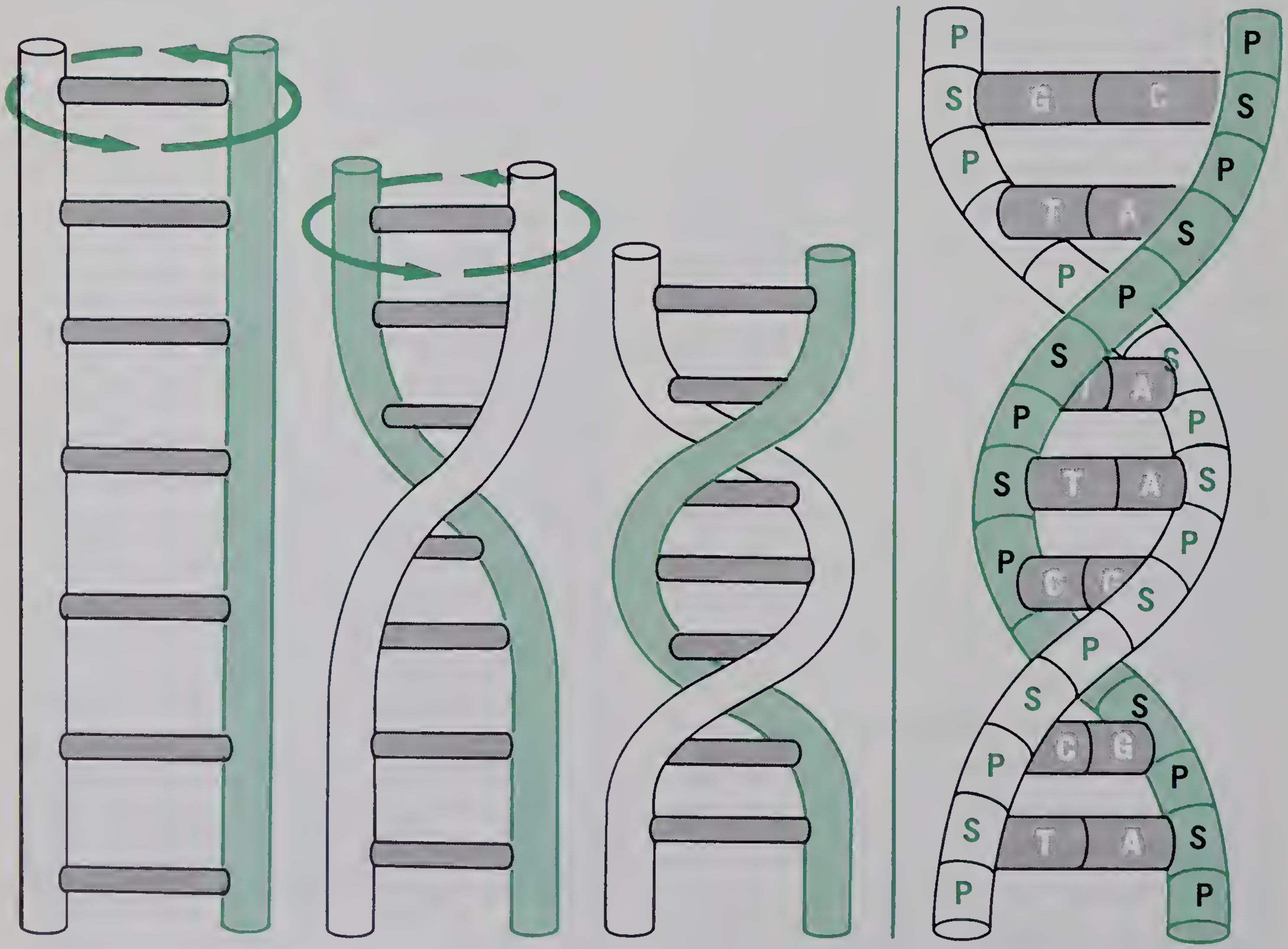
Watson and Crick described the DNA molecule as a double helix, consisting of two strands wound around each other and connected by cross pieces. You might think of it as a ladder twisted into a spiral or a corkscrew. While we speak of DNA as a molecule, it is actually a super molecule composed of numerous smaller molecules.

If we return to the spiral ladder comparison, the strands forming the side pieces are composed of alternating units of *deoxyribose sugar*, a five-carbon sugar, and *phosphates*. The links between these strands, or steps of the ladder, are composed of pairs of nitrogen-containing *bases*. These bases consist of four kinds of organic molecules, belonging to two classes of compounds, as follows:

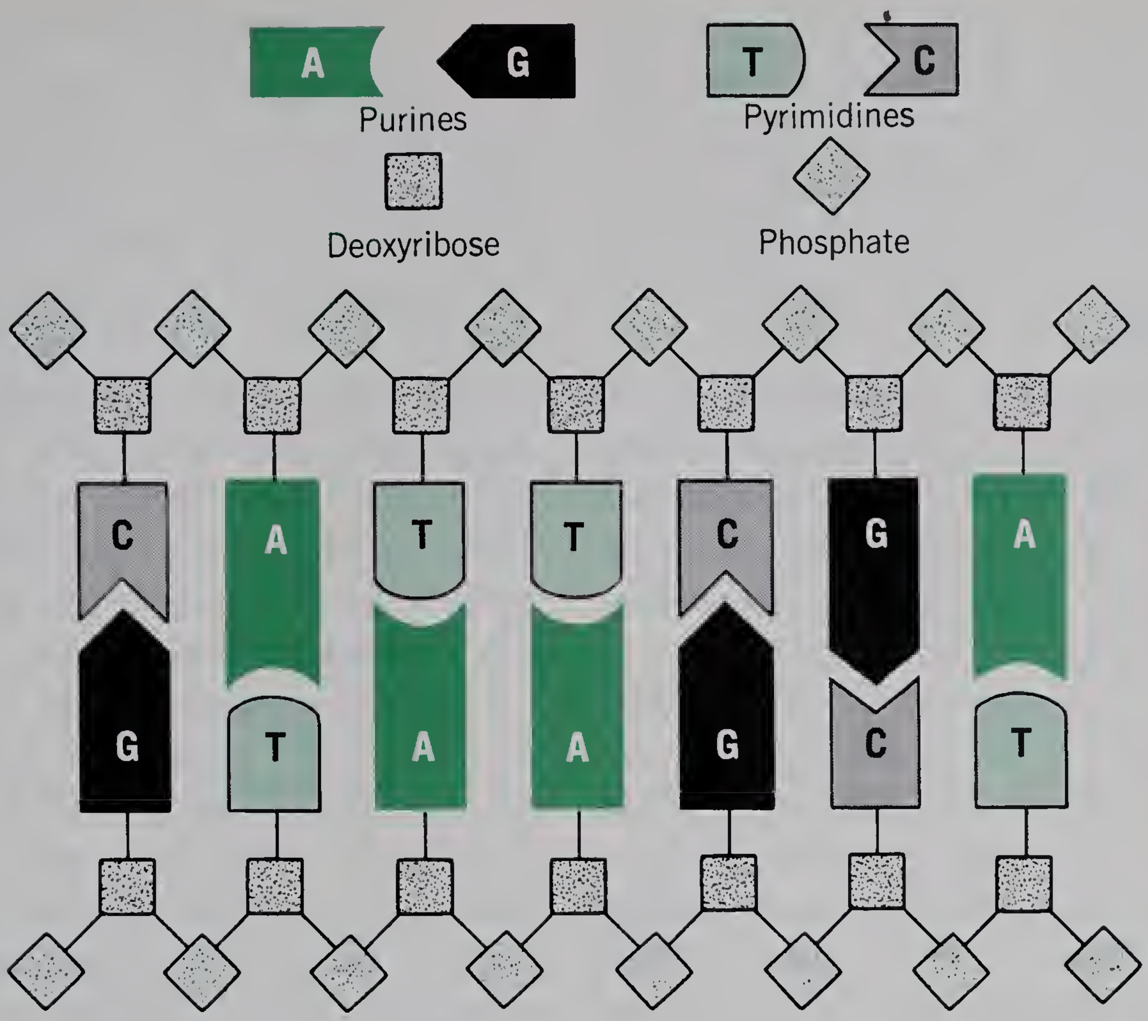
The *purines* (*pyur*-eens) include *adenine* (*ad*-en-een) and *guanine* (*gwahn*-een) molecules.

The *pyrimidines* (py-*rim*-i-deens) include *thymine* and *cytosine* (*syt*-o-seen) molecules.

Watson and Crick found that there is a definite pattern in which these base molecules link in pairs. Adenine is joined to thymine, while guanine is linked to cytosine. Notice that one of each pair is a purine and the other a pyrimidine. These base pairs are in



3-15 The first three diagrams show how a double helix might be formed by twisting a flexible ladder. The last diagram shows the basic structure of the DNA molecule according to the Watson-Crick model.



3-16 An uncoiled portion of the DNA molecule, with its parts abbreviated as letters.

turn fastened to sugar molecules in the side pieces, or helical strands.

If you pulled two strands of a DNA molecule apart by separating the base pairs, you would have a series of units consisting of a sugar unit, an attached purine or pyrimidine, and a phosphate group. This portion of the molecule is called a ***nucleotide.*** Thus, you might think of a DNA molecule as a double row of nucleotides joined by their base molecules.

An uncoiled DNA molecule with its component parts abbreviated as letters is shown in Fig. 3–16. Notice how the nucleotide units fit together as the base pairs are joined. Notice also that A and T are always joined, as are G and C, although their positions (right and left) may vary. There is also variation in the linear sequence of the base pairs. This is important in the genetic function of DNA, as you will see in Unit Two.

A second nucleic acid known as ribonucleic acid, or **RNA,** is a near duplicate of DNA. The sugar in this molecule is *ribose* rather than deoxyribose (it contains one more oxygen atom), and *uracil,* another pyrimidine, is substituted for thymine in the composition of its bases. RNA is a product of DNA and serves as its agent in controlling certain cell activities. We will return to these nucleic acids in the discussion of the cell and its chemical activities.

DNA – the key to life. DNA is unlike any other substance in the world. Life is a unique condition because DNA is a unique molecule. In what ways is it unique? Let us consider some of the characteristics of this remarkable molecule.

A DNA molecule is capable of making an exact duplicate of itself by a process known as ***replication.*** Can a water molecule form another water molecule, a sugar molecule organize another sugar molecule, or a protein molecule another protein molecule? We say that life is self-perpetuating or that living matter can form more living matter. Actually, it is the DNA which is self-perpetuating.

DNA, in the composition of its nucleotides, bears the genetic code that determines exactly what an organism will become. We say that like produces like. What we really are saying is that like DNA produces like organisms.

DNA, together with its product RNA, controls the organization of enzymes. These in turn determine all of the chemical activity of the cell. When we say that living things have a unique chemical organization, we are really saying that DNA molecules regulate all the possible phases of cell biochemistry.

From time to time DNA molecules make chemical mistakes during replication. A different DNA molecule appears and transmits its new structure to other molecules as it replicates. A genetic variation in an organism results. Occasionally the variation is beneficial to the organism, or it may be unfavorable or even fatal. If the organism reproduces, the change is transmitted to the offspring. Thus organisms do not remain in a static form age after age. There is always the possibility of improvement of life through variation in the structure of DNA molecules.

As you proceed through your course in biology, DNA will come into the discussion time after time. How do organisms grow? How do they reproduce? How does a species maintain its identity? Why do new organisms resemble their parents in some respects and differ in others? DNA provides the answers to all of these questions. DNA is the key to life.

IN CONCLUSION

The story of the chemical basis of life is an account of progressive changes in the organization of matter — an elevation to higher and higher levels of complexity. Consider the basic particles that form the hydrogen atom and build up through all possible proton and electron arrangements and numbers to uranium, the 92nd element. Through all of this series of natural elements, matter becomes more complex. Then consider the grouping of atoms in the simpler inorganic compounds as covalent and ionic bonds raise matter to a higher level of complexity. When organisms arrived on the scene at some time in the distant past, an entire new form of compound came into being, organized around carbon atoms by chemical changes in living organisms. Of course, DNA and RNA came first. How and from what, we may only guess and theorize. Perhaps we will have this answer some day. Perhaps we never will.

We now proceed to cells, the basic units of life — the living products of DNA.

BIOLOGICALLY SPEAKING

atom
atomic mass
atomic number
biosynthesis
carbohydrate
coenzyme
colloid
compound
covalent bond
DNA
electron
element
energy
enzyme
fat
hydrolysis
inorganic
ion
ionic bond
ionization
isotope
matter
mixture
molecule
neutron
nucleotide
nucleus
organic
protein
proton
RNA
replication
solution
suspension

QUESTIONS FOR REVIEW

1. Distinguish between a physical change and a chemical change.
2. Give an example of conversion of potential energy to kinetic energy.
3. Describe the location of protons, neutrons, and electrons in an atom.
4. Distinguish between the atomic number and the atomic weight of an element.
5. What are isotopes?
6. What part of an atom determines its chemical activity?
7. Distinguish between covalent bonding and ionic bonding in the formation of a compound.
8. Give an example of a molecule which is not a compound; a compound which is not molecular; a molecular compound.
9. Summarize the properties that distinguish a compound from a mixture.
10. Explain the relation of a solvent and a solute in a solution.
11. Distinguish between a molecular solution and an ionic solution.
12. What factor determines whether a substance will form a solution, a suspension, or a colloid?
13. Describe phase reversal in a colloid. How may external conditions cause phase reversal?
14. Distinguish between a reversible and an irreversible colloid.
15. List the inorganic compounds which supply the essential elements to organisms.
16. What is biosynthesis?
17. Distinguish between monosaccharides, disaccharides, and polysaccharides.
18. What two basic units compose fat molecules?
19. Explain the relationship of amino acids to protein molecules.
20. What is an enzyme?
21. Describe the units of a DNA molecule and their relation to one another.
22. Which groups in a DNA molecule are constant in its structure? Which groups are variable?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the increase in the complexity of matter through the series of natural elements.
2. Discuss the key position of carbon in the organization of organic compounds.
3. Discuss the vital role of enzymes in biochemistry.
4. If you were to select one of the substances you have studied as "the living substance," which one would be your choice? Justify your selection.
5. Why is replication an extremely important property of a DNA molecule?
6. Discuss the role of DNA in determining what an organism is to be and in producing variations in organisms.

CHAPTER 4

THE STRUCTURAL BASIS OF LIFE

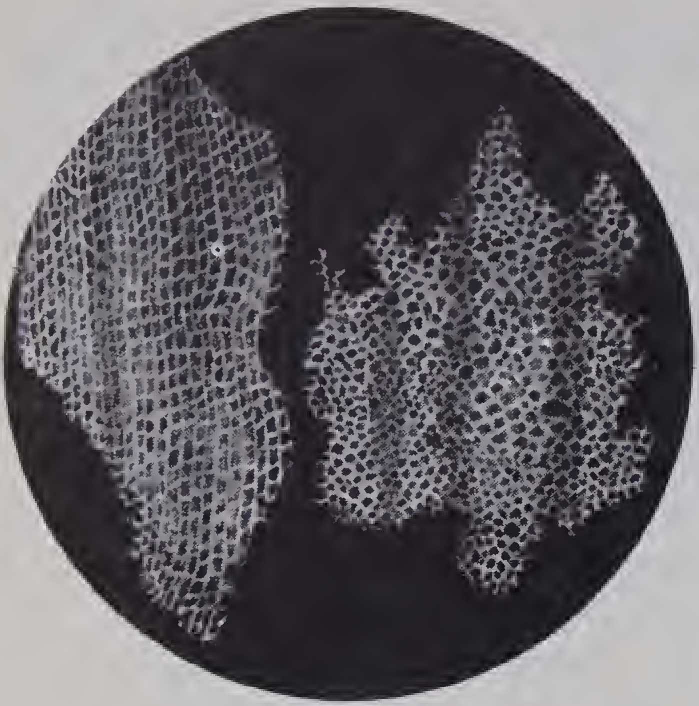
Having become familiar with the various elements and compounds, both inorganic and organic, found in organisms, we shall now consider how these materials actually compose a plant or animal. The cell is the structural unit of life. All the materials in an organism are organized into specific cell structures. In this organization these materials cease being mere chemical substances and become living matter.

A real knowledge of cellular biology is essential in any area of biological study. Nearly all the specialized branches of biology relate in some way to cells. Physical scientists ushered in the atomic age as a result of exhaustive studies of molecules, atoms, alpha particles, beta particles, and other invisible forms of matter. Equally important biological discoveries have come from our nation's laboratories where biologists are finding out more and more about the basic unit of life, the cell.

Three hundred years of cell exploration. Three hundred years ago, in the year 1665, the British scientist Robert Hooke (1635–1703) discovered cells. His material was a piece of cork sliced thin enough to let light pass through it for his microscopic examination. To his surprise he found that the cork consisted of a mass of tiny cavities. Each cavity was enclosed by walls, reminding him of cells in a honeycomb. ***Cell*** was a logical name for these structures, which he described in a report of his discovery titled *Micrographia.*

Hooke did not realize, however, that the most important parts of these cells were lacking. He saw only the empty shells of cells that had once contained active, living materials. Having made this discovery, it is surprising that Hooke did not follow it up with an examination of many other parts of plants or animals in which he might have seen cell content. But 170 years passed before another scientist made a significant discovery relating to cells.

In 1835 the French biologist Dujardin (*doo*-jar-dahn) viewed some living cells with a microscope and found that they had content. Dujardin named this material *sarcode,* a term later to be changed to protoplasm. Three years later the German botanist Matthias Schleiden proposed, as a result of extensive studies, that all plants are composed of cells. The following year Theodor Schwann, a German zoologist, made a similar statement regarding animal structure. The work of these men, together with the contributions of other 19th



4-1 Hooke's drawings of thin sections of cork; longitudinal (left) and cross section (right). (Bettmann Archive)

century biologists, established the ***cell theory***, which states that:

1. The cell is the unit of structure and function of all living things.
2. Cells come from pre-existing cells, by cell reproduction.

For the next 100 years biologists added greatly to our knowledge of cells and their activities. Their work, however, was confined by the magnification limits of the light microscope. About 20 years ago a new era of understanding of cell structure and physiology was ushered in with the electron microscope. New techniques provided additional tools for analyzing the cell structures that the electron microscope revealed. High speed centrifuges separated cell materials, and advanced methods in biochemistry determined their chemical make-up and molecular structure. By means of new techniques in microsurgery, biologists actually removed cell structures for isolated study. Radioactive isotopes, serving as tracer elements, allowed biologists and biochemists to follow the course of chemical reactions through the machinery of the cell and relate them to specific cell structures. As a result, we have learned more about cells in the past 10 years than biologists were able to learn in the previous 290 years or more!

Today we are discussing cells in an entirely new light. Life has taken on new meaning. We believe we finally have the answers to many questions about the organization and activity of living cells. However, reliable as our evidence may seem, we must remember that many of these concepts are still based on hypotheses and not on facts. We may revise our knowledge of cells many times in the years to come, but each new discovery will bring us nearer to an understanding of the marvels of a living cell.

Cells – the basic units of life. All the substances composing an organism are contained in its cells. Thus each cell is a unit mass of protoplasm, or the individual part of which the whole organism is composed. The simplest organisms consist of but one cell. Organisms above this level of organization may be made up of thousands, millions, or even billions of cells. It has been estimated that the human body contains more than 50 thousand billion cells. The size of the organism is determined not by the *size* of its cells but by their *number*. Elephant cells are no larger than ant cells. There are just more of them. Large or small, simple or complex, the cell is the unit of structure and function of all living organisms.

Processes of a cell. All of the processes of a living cell involve energy transformations. The source of all of this life energy is chemical activity within the cell. It is difficult to separate one cell activity from all the others which are closely related and occurring simultaneously. Similarly, there are specialized cell parts, each of which is concerned with one or more of the vital chemical reactions. Thus, in discussing the cell, we cannot separate structure from function. However, even an artificial separation of the total chemical activities into phases or processes simplifies a discussion of cell structures and their associated functions. We shall summarize the processes of a cell as follows:

Nutrition. Food molecules are necessary to support the processes of the cell, as well as to form its substances. Some cells manufacture their own food molecules. Others receive them from the environment.

Digestion. Certain enzymes synthesized in the cell accelerate chemical reactions and simplify food for cell use.

Absorption. Water, food molecules, ions, and other essential materials are transported into the cell from its environment.

Synthesis. Cells organize their own specific proteins. Synthesis of these complex molecules from amino acids is controlled by DNA and RNA. The result of these activities is growth and regulation of all chemical activity of the cell by enzyme action.

Respiration. Energy is released in the cell when certain organic molecules, especially glucose, are split, or degraded. This chemical energy is essential in maintaining life.

Excretion. Various waste materials are formed as by-products of cell activities. These substances pass from the cell to its environment.

Secretion. Certain cells synthesize molecules which influence the activity of other cells. Such cell secretions include vitamins and hormones.

Movement. Some of the energy released in a cell is used in movement. This may occur as flowing of the cell content, locomotion of the cell by means of special structures, or cellular contractions, as in muscle cells.

Response. External conditions such as heat, light, and physical contact alter the activities of a cell and cause a response.

Reproduction. A cell divides its mass periodically. In this manner the number of cells increases or new organisms are formed.

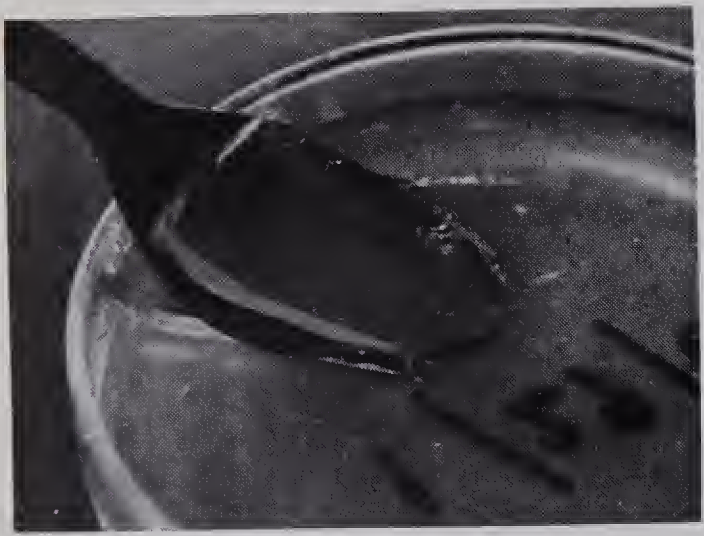
Parts of a cell. In classifying the parts of a cell, we may divide them into specific structures, as follows:

1. The *nucleus*, including the: a. nuclear membrane, b. chromosomes, c. nucleolus.
2. The *cytoplasm* (*syt*-o-plaz-m), including the: a. plasma membrane (cell membrane), b. vacuolar membrane, c. endoplasmic reticulum, d. ribosomes, e. mitochondria, f. Golgi bodies, g. plastids, h. vacuoles.
3. The *cell wall*, including the: a. middle lamella (intercellular layer), b. primary wall, c. secondary wall.

Structure of the nucleus. We will begin our discussion of the parts of a cell with the ***nucleus***, the control center of all cell activity. When a cell is stained for microscopic examination, the nucleus stands out as the most prominent part. It is usually spherical or oval in shape and often lies near the center of the cell.

The nucleus is bounded by a thin ***nuclear membrane*** which separates the nuclear materials from other parts of the cell. However, the nuclear membrane is not a barrier. What appears to be a skinlike covering under the light microscope shows as a porous structure under the electron microscope. Nuclear materials pass freely into the surrounding cell substance.

4-2 Nutrient agar in sol and gel phases may be used to illustrate the colloidal nature of protoplasm. Above: at about 98° C the agar in the sol phase flows like a liquid. Below: at about 40° C the gel phase forms. (Richard F. Trump)



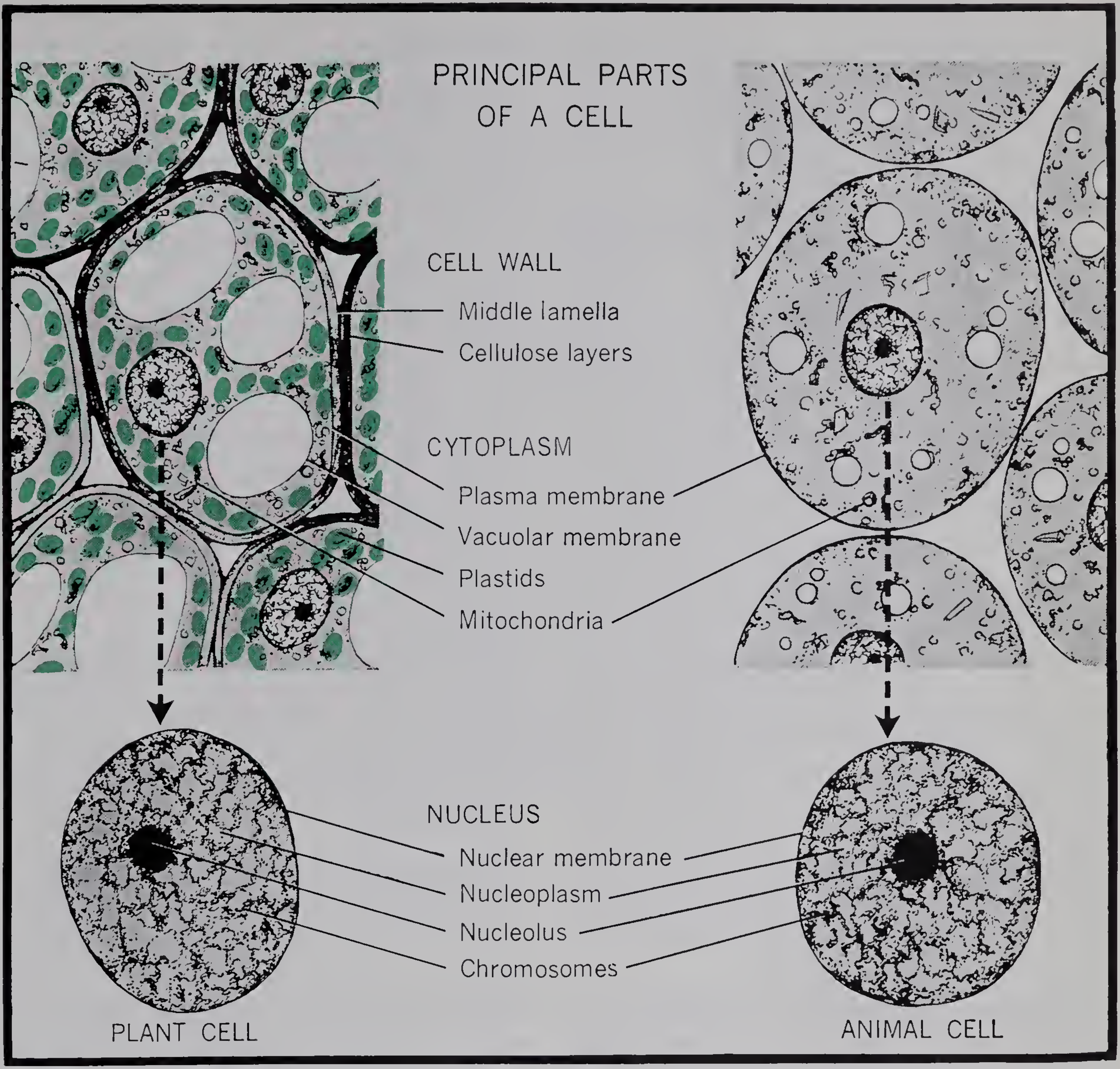
The nucleus contains a viscous colloid, rich in protein, which is often referred to as *nucleoplasm.* It also contains one or more spherical bodies called ***nucleoli.*** Embedded in the nucleoplasm are numerous fine strands called ***chromosomes.*** Chromosomes are composed of DNA joined to protein molecules to form nucleoproteins. DNA molecules are the key components of chromosomes. As you learned earlier, these molecules act as the genetic code of the organism. As a result they are the most vital parts of the cell. Perhaps you wonder how DNA, located in the nucleus, can control all of the activities of the cell when they occur outside the nucleus.

In recent years biologists have found evidence that DNA synthesizes a near duplicate molecule known as RNA. We referred to this nucleic acid in Chapter 3. Each RNA molecule bears a genetic code identical to the DNA molecule that organized it. RNA molecules pass through the nuclear membrane into the cytoplasm. Here they control the organization of enzymes according to the genetic code supplied them by DNA. These enzymes in turn control the synthesis of specific proteins and all other chemical activities of the cell.

Structure of the cytoplasm. We refer to the cell substances outside the nucleus as ***cytoplasm.*** Under the light microscope, cytoplasm appears as a semifluid material filling most of the cell. It often flows through the cell in a manner we call *streaming.* As it changes position in the cell, it may revert from sol to gel and back to sol. The nucleus often flows with the cytoplasm and changes shape as it moves.

The exposed outer edge of the cytoplasm forms a thin molecular layer known as the ***plasma membrane,*** or *cell membrane.* This thin boundary separates the cell from neighboring cells and from the fluids that bathe it. But like the nuclear membrane it is not a barrier, for molecules pass through it. However, the plasma membrane is the vital regulator of this molecular traffic. It is selective in allowing certain molecules to pass through and rejecting others.

The plasma membrane forms where the colloidal cytoplasm borders on another substance, such as a fluid outside the cell. We speak of this boundary as an *interface.* Molecules rearrange along the interface and form a thin, gelatinous layer. You might compare the for-


PRINCIPAL PARTS OF A CELL
CELL WALL
Middle lamella
Cellulose layers
CYTOPLASM
Plasma membrane
Vacuolar membrane
Plastids
Mitochondria
NUCLEUS
Nuclear membrane
Nucleoplasm
Nucleolus
Chromosomes
PLANT CELL
ANIMAL CELL

4-3 Diagrams of typical plant and animal cells. Remember that cells are actually three dimensional and that it is difficult to portray them accurately on a flat surface.

mation of a plasma membrane with the skim that forms on the surface of soup or hot chocolate as it cools. Extremely high magnifications by the electron microscope have revealed that a plasma membrane is not a simple, smooth, skinlike structure, as it appears under the light microscope. It is not a single molecular layer but a layer several molecules thick. The inner and outer layers of the membrane are composed of protein molecules. Between these is a double layer of fatlike molecules. The membrane surface is intricately folded with pouches extending inward and blisters bulging outward. The infolded pouches are tiny gateways through which solid materials may pass through the membrane, as you will discover in the next chapter when we discuss the cell and its environment. If a plasma membrane is pierced or cut, cytoplasm may ooze through the opening for a short time. Soon, however, other molecules move into position and plug the opening. This rapid repair occurs frequently as large particles pass through the membrane into the cell.

A membrane similar to the surface plasma membrane forms along an interface where cytoplasm borders on a central cavity within a cell. Because of its location we refer to this membrane as a ***vacuolar membrane.***

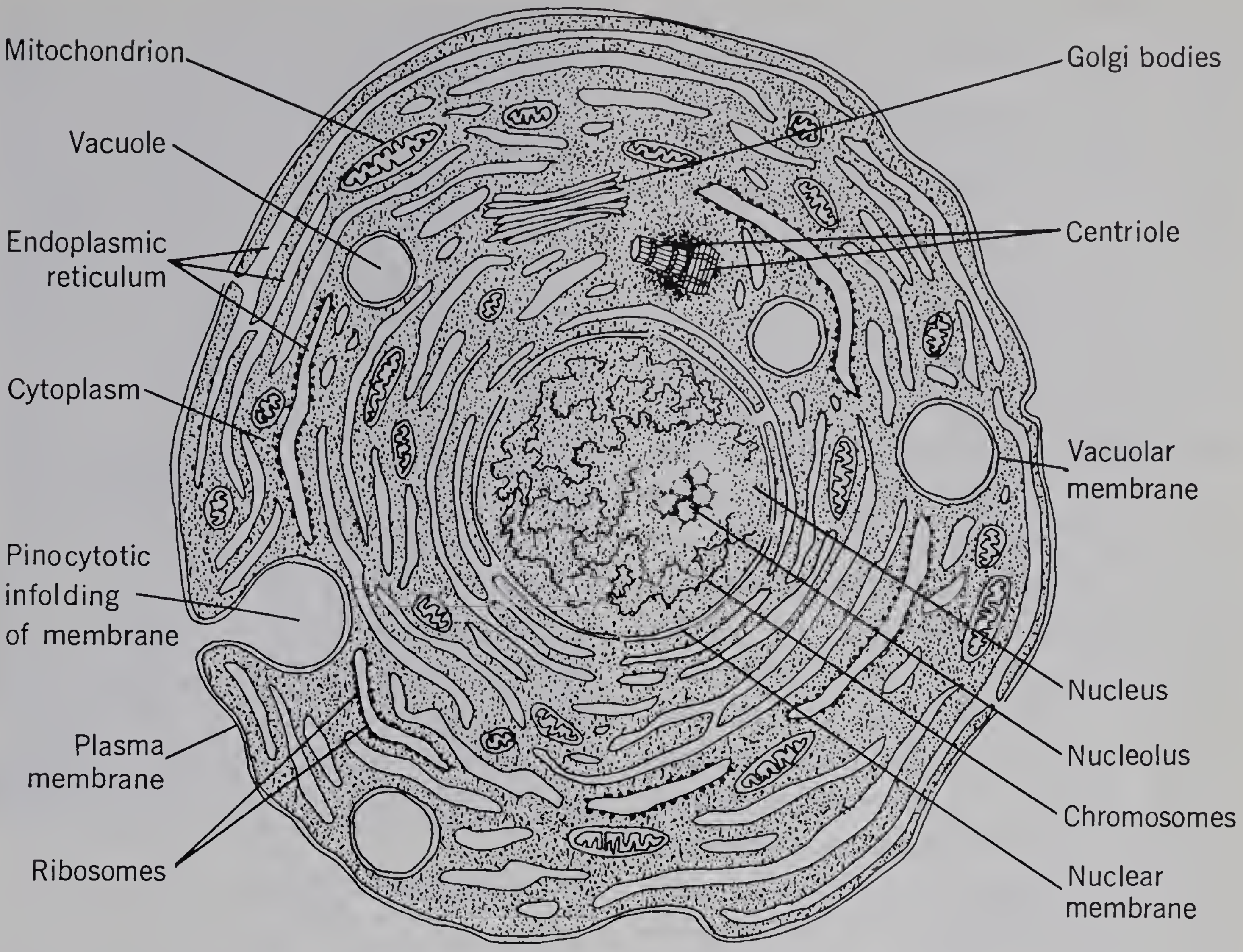
The electron microscope has revealed another characteristic of cytoplasm, unknown until recent years. Under the light microscope, cytoplasm appears as a uniform, semifluid material containing numerous granules. However, a magnification of 40,000 times or more shows a much more intricate structure. Cytoplasm contains a complex system of membranes which tend to lie parallel to one another. This network, or ***endoplasmic reticulum,*** fastens to the plasma membrane and nuclear membrane. Biologists believe that the endoplasmic reticulum may be a system of tubes through which materials pass from the plasma membrane to the nucleus. However, this is only a reasonable guess, since the function of the endoplasmic reticulum is not yet known.

Cytoplasmic organelles. Various organized bodies are present in the cytoplasm. We refer to these specialized structures as ***organelles,*** which means "little organs." Certain of these cell organelles are visible under the light microscope. Others are so small that they were not known to exist before we had the electron microscope. Each of these structures is associated with a specific process or activity of the cell. In our present investigation of the cell, we are concerned primarily with their structure, composition, and location. In chapters to follow, we will explore their chemical activity in greater detail.

Under extremely high magnification with an electron microscope, tiny dense granules may be seen attached to the endoplasmic reticulum and lying between its folds. These bodies are the ***ribosomes,*** so named because of the large amount of RNA they contain. In addition to RNA received from the nucleus, ribosomes contain protein-synthesizing enzymes. Recent studies indicate that they are the protein factories of the cell. Thus, while they are among the smallest of all cell structures, their function is among the most vital.

The electron microscope also reveals the detailed structure of rod-shaped bodies in the cytoplasm. These are the ***mitochondria*** (*myt*-o-*kahn*-dree-a). They are known to be centers of cellular respiration, during which energy is released to support cell activities. The mitochondria are the powerhouses of the cell. A mitochondrion is enclosed in two membranes, each consisting of a layer of protein molecules and a layer of fat molecules. The inner membrane folds inward at various places forming partial partitions within the mitochondrion. This infolding increases the surface area of the membrane. We refer to these partitions as *cristae*. Mitochondria are known to contain enzymes that split organic molecules and transfer energy to other compounds from which it is released in the cell.

The function of certain cell structures remains a mystery. Among these cell unknowns are the ***Golgi bodies*** (*gol*-jee), or Golgi apparatus. They were first seen in 1898 in nerve cells by the Italian neurologist Camillo Golgi. The electron microscope has revealed much more of their structural detail than Golgi was able to determine, but this knowledge has provided little or no clue to their function. Golgi bodies appear as small groups of parallel membranes in the cytoplasm near the nucleus. The membranes form plates with channels along their edges. The fact that they


Mitochondrion
Vacuole
Endoplasmic reticulum
Cytoplasm
Pinocytotic infolding of membrane
Plasma membrane
Ribosomes
Golgi bodies
Centriole
Vacuolar membrane
Nucleus
Nucleolus
Chromosomes
Nuclear membrane

4-4 A generalized cell in diagrammatic form. Most of the structures are shown larger in proportion than they are in the actual cell. This diagram is based on electron micrographs of many cells.

are most numerous in cells composing glands may indicate that they secrete special substances.

Other microscopic bodies present in the cytoplasm are known as ***plastids.*** Some plastids function as chemical factories, while others serve as storehouses of the cell. Plastids are found most frequently in the cells of plants and primitive organisms.

The most familiar plastid is the *chloroplast.* These plastids contain green pigments called *chlorophylls.* We often refer to chloroplasts as carbohydrate factories for they contain the enzymes involved in the organization of carbohydrates. Chloroplasts place the green plant in a key biological position, as most living organisms depend on the food-making activities of cells containing chlorophylls. In addition to chlorophylls, chloroplasts may contain pale-yellow pigments called *xanthophylls* (*zan*-tho-fils) and deep-yellow or reddish-orange pigments known as *carotenes.*

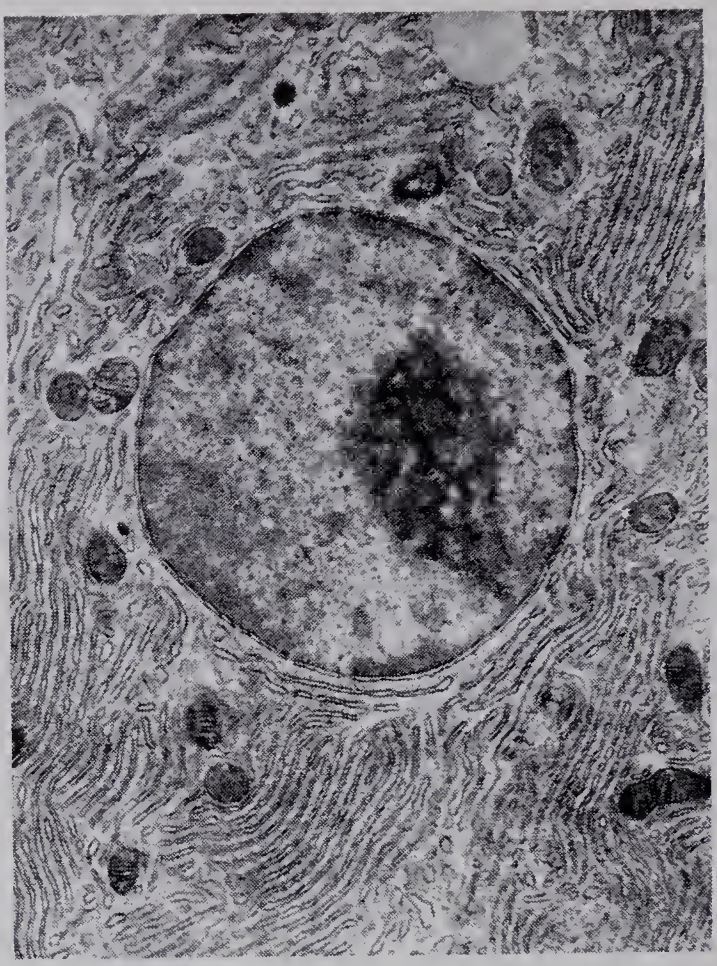
Chloroplasts vary both in size and in shape. In the cells of advanced plants, such as leaf cells, they are often disk-shaped. When viewed with a light microscope, chlorophyll appears to be distributed throughout the chloroplast. The electron microscope reveals that the chlorophyll is contained in layers of disklike protein bodies known as *grana.* The disks are held together by fatlike molecules.

Other plastids produce red and blue pigments in addition to yellow and orange. These plastids, often referred to as *chromoplasts,* are found in flower petals and in the skins of fruits such as the tomato, cherry, and pepper. In some cells chromoplasts are chloroplasts that have lost their green chlorophyll. This occurs in the ripening of a banana or a tomato when the skin changes from green to yellow or red.

Leucoplasts (*loo*-koh-plasts) are usually colorless plastids which serve as food storehouses in many plant cells. These plastids contain enzymes necessary to link glucose molecules together and form starch molecules. This may occur temporarily in chloroplasts, but leucoplasts are the principal starch storage centers. Plastids are the only centers of starch storage in a cell. Because starch is insoluble it never reaches the nucleus or the cytoplasm outside plastids. Leucoplasts may be found in the cells of roots, stems, and in other storage areas of plants. You can see large numbers of them in the cells of the white potato. It is interesting that leucoplasts may develop chlorophyll and change to chloroplasts when they are exposed to light. This may occur in the cells of the white potato.

Cell vacuoles. Plant cells frequently contain one or more fluid-filled cavities in the cytoplasm. Such cavities are known as *vacuoles.* The bordering *vacuolar membrane,* formed by the cytoplasm, regulates the molecular traffic between the vacuole and the cell substances. A young cell often contains several vacuoles which unite as the cell increases in size and form a single, large central vacuole. Pressure exerted by the fluids in the central vacuole may force the cytoplasm into a thin layer around the edge of the cell.

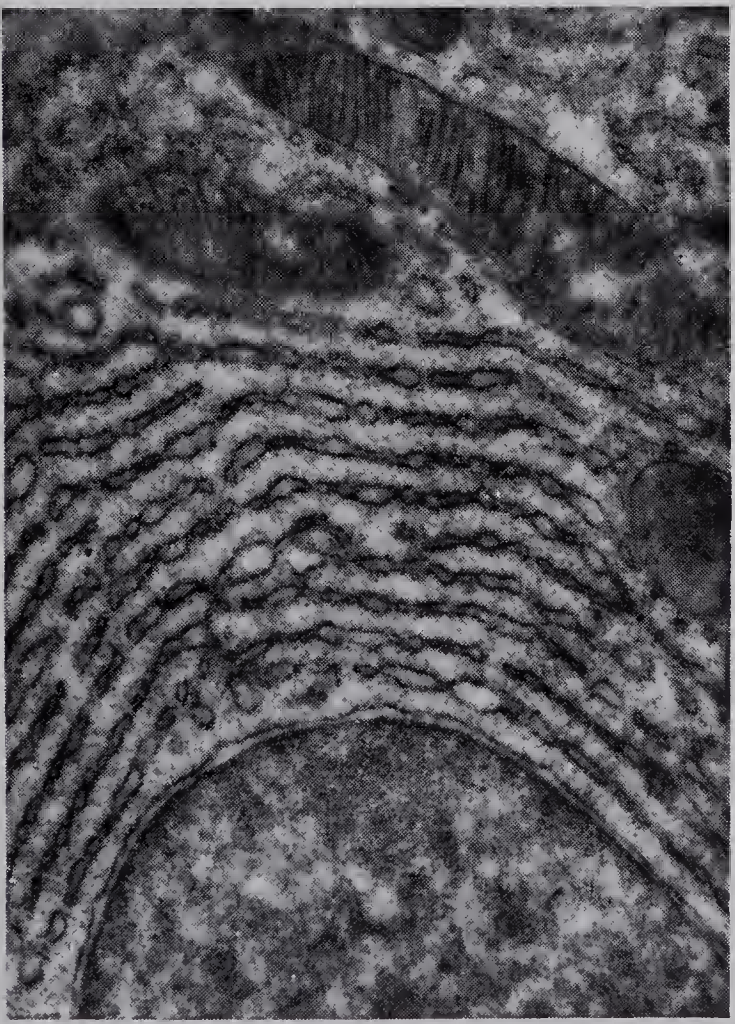
The fluid in the vacuoles of plant cells is largely water. Ions of mineral compounds, molecules of sugars and other soluble substances, and large molecules of proteins and other organic materials in colloidal suspension in the water form the content of the vacuole that we often refer to as *cell sap.* Other vacuoles may contain food materials and waste products. Still others serve as water-eliminating organelles in many one-celled organisms.



4-5 Electron micrograph of the nucleus in detail. The nucleolus is the dark mass within the nucleus. Note the apparent pores in the nuclear membrane. The darker spheres in the cytoplasm are mitochondria. (Don W. Fawcett)

Vacuoles of plant cells also contain water-soluble pigments. Common among vacuolar pigments are *anthocyanins* (*an*-thoh-*sy*-a-nins) which have shades of scarlet, crimson, blue, purple, and violet. These pigments provide the red shades of autumn leaves, the purple of the turnip top, the red of the radish and beet, and the petal coloration of asters, geraniums, tulips, hyacinths, and many other flowers. In the hydrangea, variations in acidity change the anthocyanin from red to blue. The formation of anthocyanins is determined by many internal and external factors. DNA regulates the production of enzymes involved in the organization of anthocyanin molecules. Thus, "roses are red and violets are blue," depending on their DNA. In addition, the accumulation of sugar seems to stimulate the production of anthocyanins. External factors include both temperature and light — usually low temperature and bright light.

The cell wall. Most plant cells are encased in an outer protective and supporting structure, the ***cell wall.*** At first glance a cell wall may appear as a single layer, but it is usually composed of several distinct layers. Where two cells lie against each other, each has formed a portion of the wall separating them. The layers of cell walls have been compared to the plastered walls separating two rooms. The center of the wall is like the layer of plaster board. This portion of a plant cell wall is referred to as the *intercellular layer,* or *middle lamella.* It contains various *pectin* (*pek*-tin) substances which are jellylike in texture. Many fruits, including apples, contain a large amount of pectin, which is released during cooking and forms a jelly as it cools.



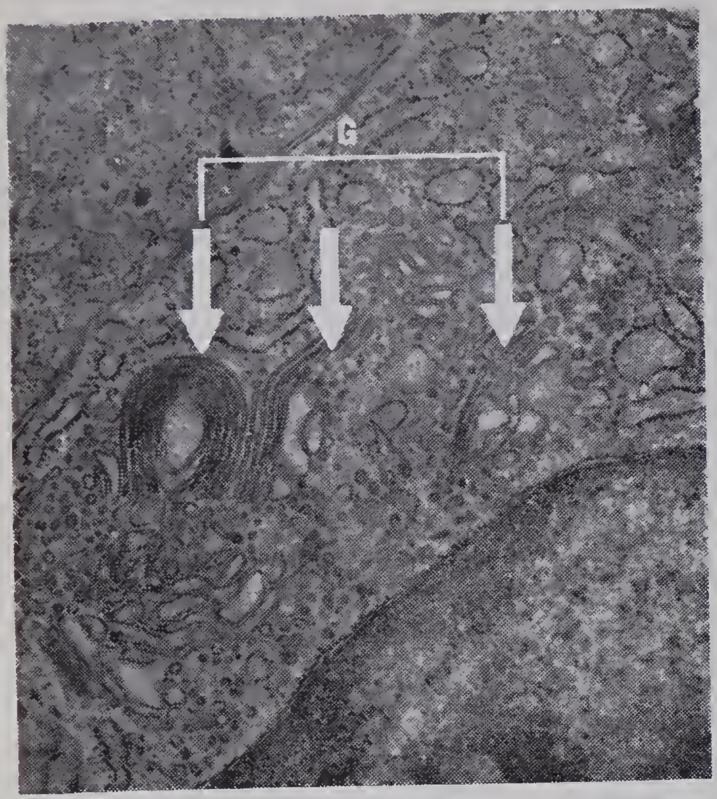
4-6 Electron micrograph showing: top, mitochondria; center, endoplasmic reticulum; bottom, nucleus. (G. E. Palade and *Journal of Cell Biology*)

Adjacent cells form thin *primary walls* on both sides of the middle lamella. We might compare these to the first coat of plaster on each side of the wall between two rooms. The primary wall is composed of cellulose fibers and pectin. Cellulose, you will recall, is a carbohydrate similar to starch. Soft plant structures such as leaf blades, flower petals, and pulpy fruits have thin primary walls.

Additional cellulose layers are built up in *secondary walls.* These walls are firm and rigid and remain long after the cell is dead. We find thick secondary walls in the cells of wood, plant fibers, and nut shells.

In a primary wall cellulose fibers are arranged in a network. In secondary walls they are more or less parallel and crisscrossed in layers. This arrangement of cellulose fibers, as in the thin sheets composing plywood, gives these walls great strength. Spaces between the fibers contain pectin and *lignin,* a complex organic compound. Lignin, second only to cellulose in abundance in wood, adds stiffness and rigidity to cell walls.

Modern methods of cell investigation. As we have been discussing the structure and chemical composition of extremely small cellular bodies such as ribosomes and mitochondria, haven't

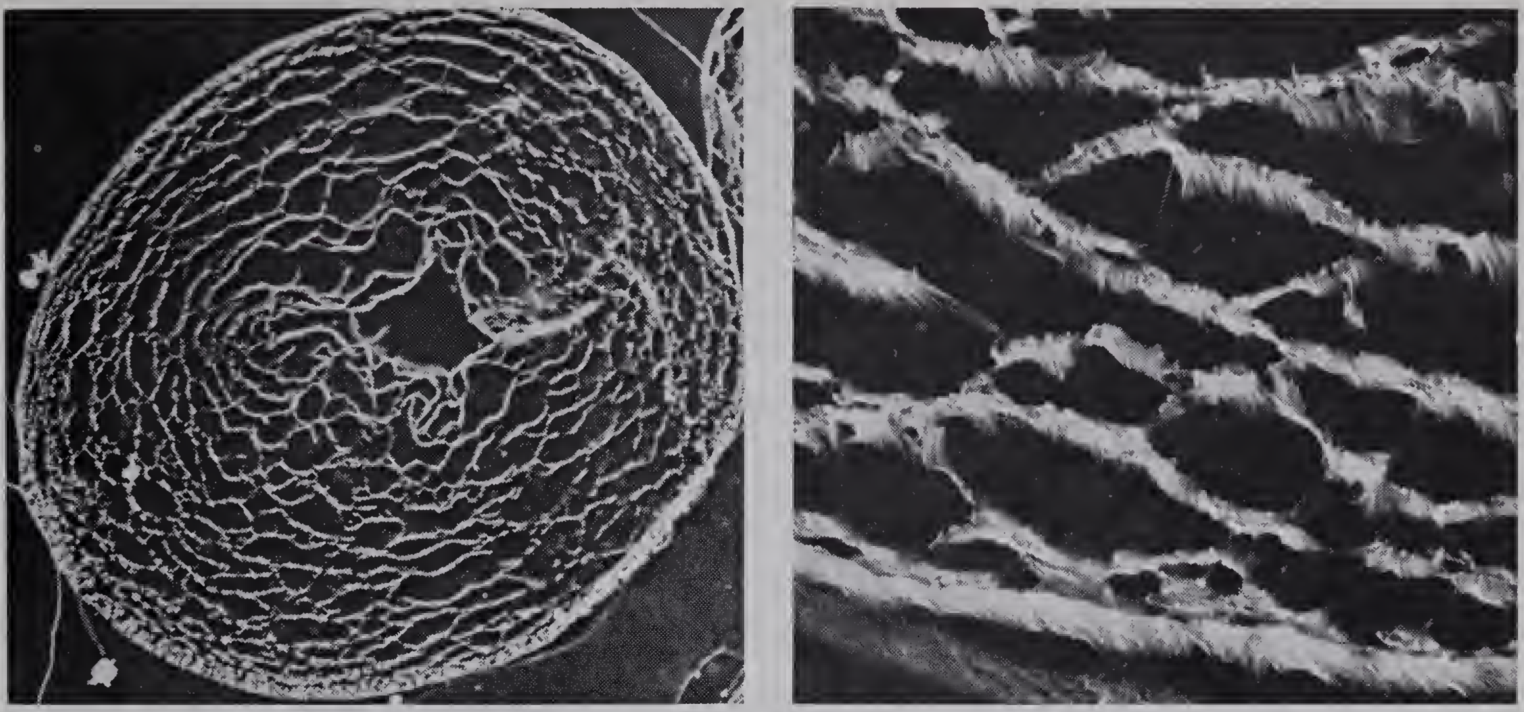


4-7 Electron micrograph showing Golgi bodies. (C. Bruni)

you wondered how biologists and biochemists have made these remarkable discoveries? We can enlarge a cell 40,000 times or more with an electron microscope and see formerly invisible structures. But how could these minute bodies be separated from other cell structures for chemical analysis? In one method cell materials are pulverized with fine sand supplying the cutting edges. The pulverized material is then placed in a centrifuge tube and spun at high speed. Various cell substances and organized bodies have different masses and densities — that is, they differ in size and weight. During high speed centrifugation, centrifugal force separates them into different layers in the tube. The most dense materials, including intact cells and nuclei, occupy the bottom layer in the tube. Next might be a layer of plastids, then a layer of mitochondria. Since the ribosomes are among the smallest cell structures, they would occupy a layer near the surface, along with pieces of the endoplasmic reticulum. Finally, the layer nearest the top would contain water and various cell fluids. The biologist may then remove material from any layer of the centrifuge tube and find a concentration of the specific cell materials he wishes to examine or analyze.

Although centrifugation separates cell structures, it does not show what is going on in the intact, living cell. Recent advances in a technique called *radioautography* have aided the biologist in tracing cell processes. Radioautography is actually a form of photography. In photography light forms an image on a sensitive substance called a photographic emulsion. You will remember from Chapter 3 that certain isotopes give off radiations spontaneously. These radioactive isotopes form an image on a photographic emulsion just as light does.

In radioautography a substance normally taken in by cells is labeled with a radioactive isotope such as tritium. A slide bearing cells and the labeled substance is then treated with a photographic emulsion. After a time the slide is examined under a microscope, and the labeled substance appears as black dots. Thus if the substance has been taken into the nuclei of the cells, black dots will appear in the nuclei. The number of black dots indicates the amount taken up. You can see that by this method it is possible to determine what part of the cell takes up the labeled substance, and how much. For example, a substance known to be used in the synthesis of DNA may be labeled with tritium. If black dots appear in the nucleus of certain cells on the treated slide, it can be assumed that DNA is being synthesized in those cells at that time. In



4-8 Left: electron micrograph of expanded cotton fiber showing cell wall layers. Right: portion of cross-section of cotton fiber enlarged still further to show fibrous texture of layers of the cell wall. (USDA, Southern Utilization Research and Development Division)

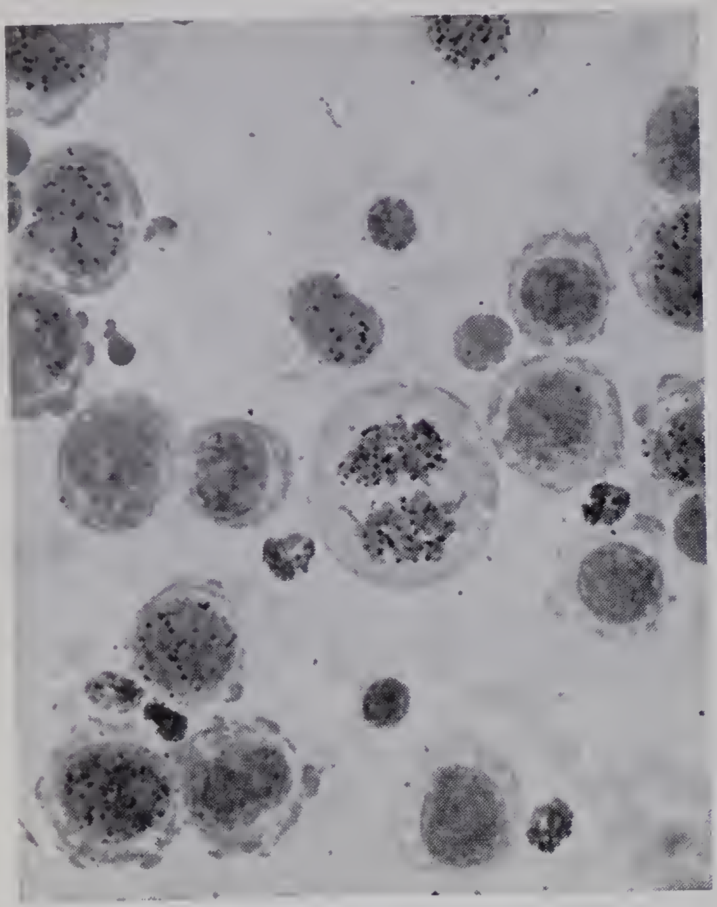
this way radioautography has revealed the location, timing, and extent of many of the processes in the living cell.

The cellular level of organization. We may consider the cell as the *first* level of the organization of living things. Since the cell is the unit of structure as well as function of living organisms, a single cell can constitute a complete organism. This is the case in ***unicellular*** organisms such as bacteria, yeasts, the ameba, and many other forms of life you will study. Some unicellular organisms are grouped together in colonies. In such ***colonial*** organisms, the cells have no direct functional relationship to one another. More complex plants and animals are composed of many specialized cells working closely together and depending on one another. Such division of labor among cells is characteristic of ***multicellular*** organisms.

Cells and the organization of tissues. When we speak of a multicellular organism, are we referring just to a large number of cells? Is your body a mere mass of billions of cells, all alike and forming a tremendous cell colony? Of course it isn't! If it were, your ability would be limited to the activity of a single kind of cell. Your body and those of complex plants and animals are the result of ***cell specialization.*** This means that there are many different kinds of cells. Each is developed for a particular kind of activity, which leads us to the subject of tissues.

We define a ***tissue*** as a group of structurally similar cells performing a similar activity. This is the *second* level of organization of living things. In your body you have muscle tissue, nerve tissue, bone tissue, cartilage, and many others. Plants also have tissues. When you name a tissue you think immediately of a certain kind of activity. Your movement is the best movement skeletal muscles can provide. Your skeleton is the best framework bone cells can provide. And your hearing, seeing, tasting, and control of your body are the marvelous activities of your nerve cells.

Each cell in a tissue is a specialist. However, while it may be structurally and chemically organized to carry on a

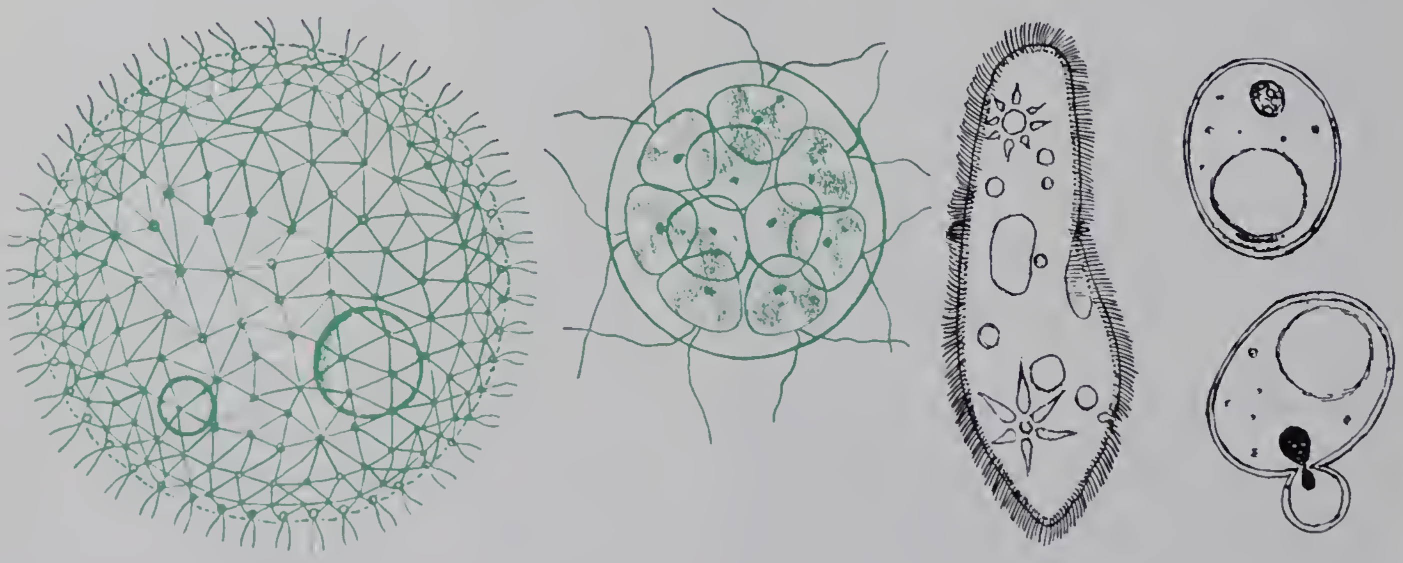


4-9 Radioautograph of cells from a mouse tumor. DNA, labeled with radioactive tritium, appears as black dots. Note that there is a concentration of dots in the nuclear material of the dividing cell (center). (Renato Baserga)

specific process with great efficiency, it must also perform all of the processes necessary to maintain its own living condition. That is, it must receive food molecules, respire, synthesize proteins and other essential substances, and generally maintain all basic life activities. In this respect it is like all other cells. But when a cell is part of a multicellular organism, there can be ***division of labor.*** A nerve cell can be a specialist in response because other cells supply its food molecules, furnish it with oxygen, and carry off its waste materials. Such interdependence might be compared to a complex society. The doctor can devote his time to medicine because he can depend on the grocer, the carpenter, the machinist, and other specialists for his nonmedical requirements. These specialists in turn depend on the doctor in matters of health. If each one were required to do everything for himself, he could never develop a specialized skill. So it is with cells.

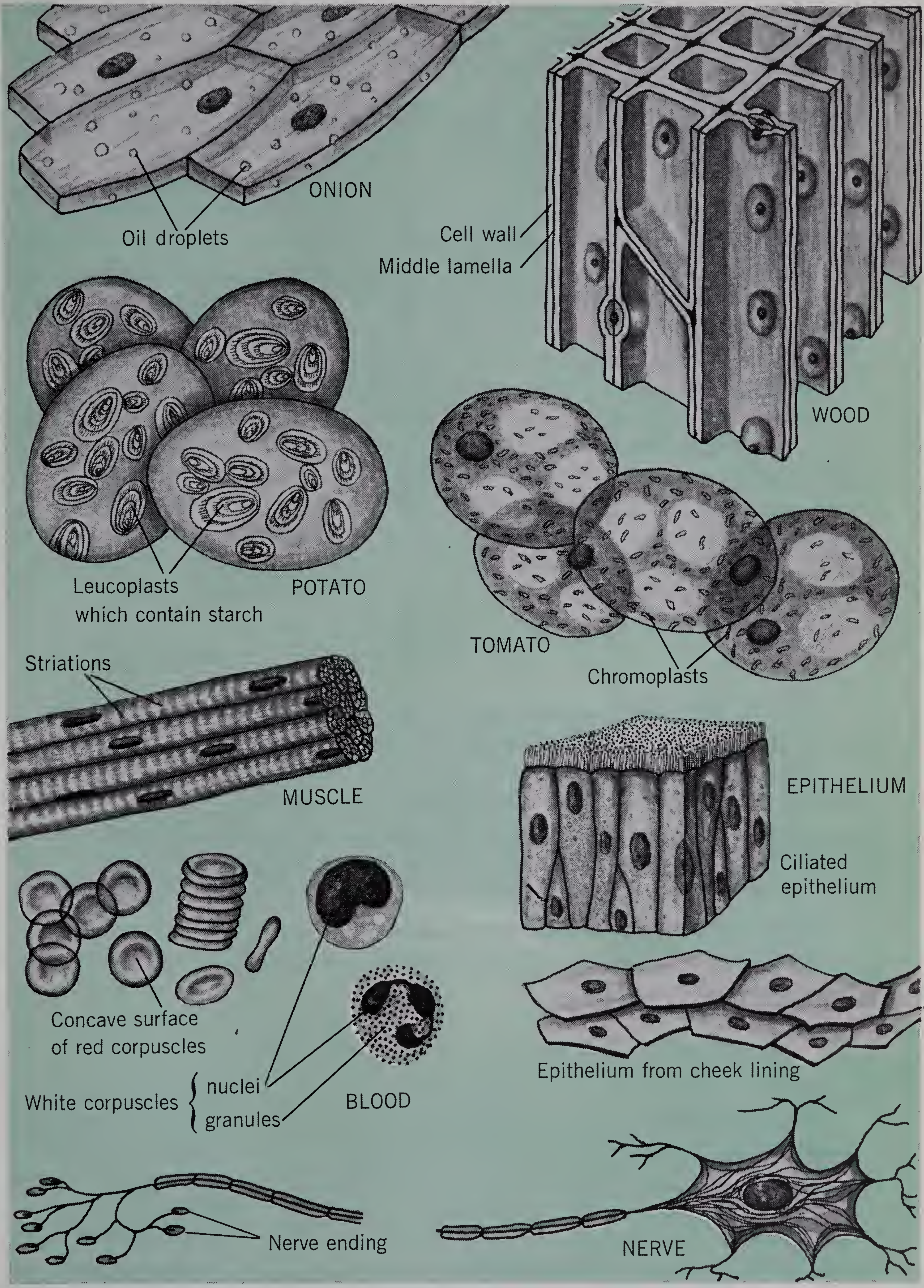
Tissues are grouped to form organs. In higher plants and animals even a specialized tissue cannot perform a life activity to perfection. This requires several tissues functioning as a unit. We call such a unit of biological organization an ***organ.*** This brings us to the *third* level of biological organization.

A hand is an organ. It is composed of skin, muscle, bone, tendons, ligaments, blood, and nerves. Your heart, stomach, liver, brain, and kidneys



Volvox Pandorina Paramecium Yeast

4-10 Unicellular and colonial organisms.


ONION
Oil droplets
Cell wall
Middle lamella
WOOD
Leucoplasts
which contain starch
POTATO
TOMATO
Chromoplasts
Striations
MUSCLE
EPITHELIUM
Ciliated
epithelium
Epithelium from cheek lining
Concave surface
of red corpuscles
White corpuscles
nuclei
granules
BLOOD
Nerve ending
NERVE

4-11 Cells are grouped as tissues in the more complex plants and animals. Note the great variety of forms that protoplasm may take.

are other organs. A plant stem is also an organ. It has bark tissues, wood, pith, and other tissues, all working together. The stem supports the leaves, flowers, and fruits, and moves materials up and down between the roots and leaves.

Organs may be grouped into systems. In the higher forms of life, especially among animals, several organs may cooperate as a functioning unit. This introduces the *fourth* level of biological organization, the ***organ system.*** For example, many organs are involved in converting a meal you eat to molecules your cells may use. How many of these organs can you name? To deliver these molecules to cells throughout your body, there must be an efficient transport system. Your heart, blood vessels, and lymph vessels perform this vital activity. In the higher animals an organ system is devoted to nearly every one of the activities involved in the living condition.

We could continue to a *fifth* level of biological organization, the *organism.* An organism is a complete and entire living thing. However, we find organisms at all levels of organization. Many never go beyond the cellular level. Others reach the tissue level but never develop organs. Still others have organs but lack well-defined systems. You will become familiar with all levels of organization as you survey the world of plants and animals — in both their primitive and advanced forms.

IN CONCLUSION

We have discussed the structural organization of organisms from molecules to cell structures. Each cell is a unit of life and in a sense a tiny living organism. As living things become more complex, cells become specialists. Tissues, organs, and systems allow cell specialization to the utmost.

Just as the cell is the unit of structure of all plants and animals, so it is the unit of their functions or chemical activities. We are now ready to explore these functions in greater detail, starting with the vital relationships between cells and their environments.

BIOLOGICALLY SPEAKING

- cell
- cell specialization
- cell theory
- cell wall
- chromosome
- colonial
- cytoplasm
- division of labor
- endoplasmic reticulum
- Golgi body
- mitochondrion
- multicellular
- nuclear membrane
- nucleoli
- nucleus
- organ
- organ system
- organelle
- plasma membrane
- plastid
- ribosome
- tissue
- unicellular
- vacuolar membrane
- vacuole

QUESTIONS FOR REVIEW

1. In one sense Robert Hooke discovered cells; in another he did not. Explain.
2. Describe the contributions of Dujardin, Schleiden, and Schwann in early studies of cells.
3. Name the two principles of the cell theory.
4. List the processes of a cell.
5. The nuclear membrane confines certain structures but is not a barrier. Why is this important?
6. Describe the formation and structure of a plasma membrane.
7. Describe the endoplasmic reticulum.
8. Locate the ribosomes in a cell and describe their function.
9. Locate and describe the mitochondria. What is their principal function?
10. Why do biologists believe Golgi bodies may function in secretion?
11. Why are chloroplasts sometimes referred to as cell factories?
12. What pigments other than chlorophyll may be present in chloroplasts?
13. Describe various contents of cell vacuoles.
14. Describe the composition of the wall of a woody plant cell.
15. What two general similarities do cells have in the formation of a tissue?
16. What is the biological meaning of the term *organism?*

APPLYING PRINCIPLES AND CONCEPTS

1. In what respect is the cell the basic unit of life?
2. Do you believe that the mere presence in a test tube of all the vital substances composing protoplasm would result in a living condition? Give possible reasons supporting your opinion.
3. Discuss centrifugation as an important research tool in the study of cells.
4. Discuss radioautography as a research tool in the study of cell processes.
5. Discuss the role of the nucleus as the control center of a cell.
6. Discuss various levels of biological organization from cells to complex organisms. In what respect is each level a higher station of development?

CHAPTER 5

THE CELL AND ITS ENVIRONMENT

Homeostasis — balance on a biological tightwire. Have you ever watched a circus performer walk a tightwire high above the heads of a crowd of tense onlookers? Every step requires precision balance. If you watch the performer closely you will notice that he leans slightly to the left or to the right to adjust his balance as he takes each precarious step. Balance and adjustment to maintain balance — these are the basic skills in tightwire walking.

In a sense every living organism walks a biological tightwire. Living things maintain an intricate balance in the face of constantly changing conditions, both internal and external. Survival depends on making adjustments to these changing conditions. We refer to the balance organisms maintain by these self-regulating adjustments as ***homeostasis***. Biologists also call this balance a *steady state*.

Homeostasis occurs at all levels in the organization of living things. It involves adjustment of the entire organism. A gopher tortoise retreats to a deep burrow through the hot summer days in southeastern United States and ventures out at night in search of food under more favorable conditions. A desert is a place of desolation under the broiling sun but a place of great activity at night when trap-door spiders, scorpions, lizards, and sidewinder rattlesnakes come out of their daytime hiding. The wall-eyed pike seeks the cool water of the depths of a lake when the summer sun heats the surface water. The frog buries in mud at the bottom of a pond to escape the cold of winter and the heat of summer. These survival adjustments are self-regulating homeostatic devices. Cells and tissues of the frog could not survive either temperature extreme. Much of your biology course will deal with adjustments of organisms to provide optimum environmental conditions for survival.

In the higher animals we find continuous homeostatic adjustments at the organ and system level. Organs function in close association with other organs in maintaining an optimum internal environment. All organs depend on heart action to supply their constant environmental requirements with circulating blood. A weakened heart, entering a state of failure, usually becomes enlarged in order to continue its vital function. A pair of kidneys normally removes cell wastes from the blood stream in the human system. If a diseased kidney ceases to function or must be removed for one reason or another, its mate enlarges, often to twice its normal size, and doubles its blood filtering capacity.

On the tissue level we find a precarious homeostatic regulation of the body fluids that bathe cells and provide the immediate internal environment. Fluids that bathe cells must supply food nutrients and oxygen and receive waste products from cell activities. Salts regulate the osmotic concentration of these fluids. A critical acid-base balance must be maintained. In such an optimum environment the survival problems of our cells are reduced to a minimum. They may specialize in such functions as sensitivity, movement, secretion, or excretion. But with this high degree of specialization, cells become more and more dependent on ideal environmental conditions.

Our lakes and streams, oceans and seas support an enormous population of one-celled and simple colonial organisms. Here we find single cells or groups of cells adjusting to extreme environmental changes. Could we expect a nerve cell or a muscle cell, removed from your body, to survive in a jar of pond water? Certainly not! Removed from the closely regulated environment of tissue fluid, these cells would perish immediately.

To what extent can cells make homeostatic adjustments and maintain their vital balance? As a first approach to homeostasis, we will consider the way in which the plasma membrane regulates the flow of materials in and out of the cell.

The molecular boundary of a cell. You will remember from your study of the cell in Chapter 4 that molecules of cytoplasm rearrange on the exposed surface and form a membranous layer. The life of the cell depends on the molecular traffic through this all-important layer. This colloidal boundary, or plasma membrane, consists of an outer layer of protein molecules, a middle double layer of fatlike molecules, and an inner protein layer. Molecules must enter continuously to supply the chemical activities of the cell substances. Other molecules, the by-products of these activities, pass outward through the membrane.

Molecules and ions move against the plasma membrane in a steady stream. Some move rapidly; others, more slowly — large molecules, small molecules, and still smaller ions. Some pass through the membrane quickly; others enter at a slower rate; while still others move through very slowly. Some do not penetrate at all. What forces regulate this molecular flow? Is it the size of the molecules? This is partly true, but some large molecules pass through more rapidly than much smaller ions. Is it the structure or composition of the membrane? This is also part of the answer. Do conditions outside the membrane or inside the cell regulate the flow? These are also important factors. Each one has an important influence on the vital relations between the cell and its environment.

The structure of this membrane is of extreme importance in regulating molecular movement through it. While the membrane may appear skinlike under the microscope, it is apparently porous. Undoubtedly, there are numerous spaces between the various molecules composing it. This would explain why very large molecules such as proteins do not pass through the membrane, while smaller ones penetrate more freely.

Another requirement for passage of most substances through the plasma membrane is that they be soluble in

THE CAPACITY OF VARIOUS SUBSTANCES TO PENETRATE THE PLASMA MEMBRANE

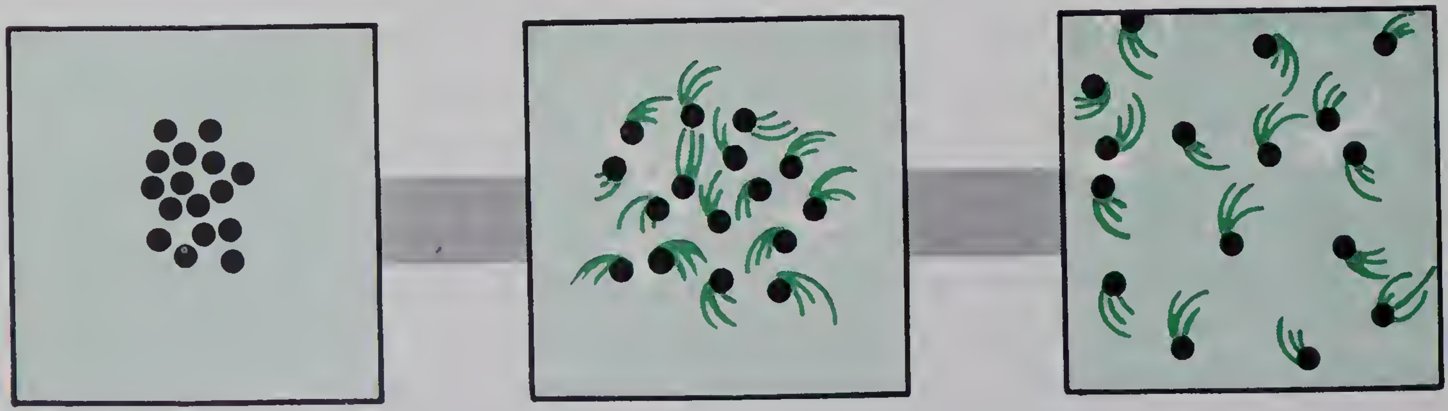
Rapid Penetration	*Slower Penetration*	*Very Slow Penetration*	*Little or No Penetration*
Gases Oxygen Carbon dioxide Nitrogen Water Fat solvents Alcohol Ether Chloroform	Monosaccharides Glucose Fructose Galactose Amino acids Fatty acids Glycerol	Disaccharides Sucrose Lactose Maltose Ions of Mineral salts Acids Bases	Polysaccharides Starches Cellulose Proteins Lipids (fats) Phospholipids

water. A cell is usually bathed in a water solution containing dispersed molecules and ions. A material which forms a colloid in water cannot pass through, nor can insoluble substances such as starches, which do not disperse among water molecules.

Permeability of membranes. If a substance passes through the membrane, we say that the membrane is ***permeable*** to that substance. However, as we have pointed out, a plasma membrane allows some substances to penetrate freely, while others pass through at varying rates and still others are rejected entirely. This variation in the rate and degree of penetration is a property of a ***differentially permeable*** membrane, the type that encloses a cell.

The rate of penetration of various molecules is very important in *absorption*, or the transport of substances through the plasma membrane from the environment into the cell. It is also vital in *excretion*, or the transport of molecules through the membrane from the cell into the surrounding external fluids.

We can classify various substances into groups, based on the rate and degree of their molecular penetration of a plasma membrane (see table above). What factors determine the rates and degree of penetration of these and other substances? Some are purely physical



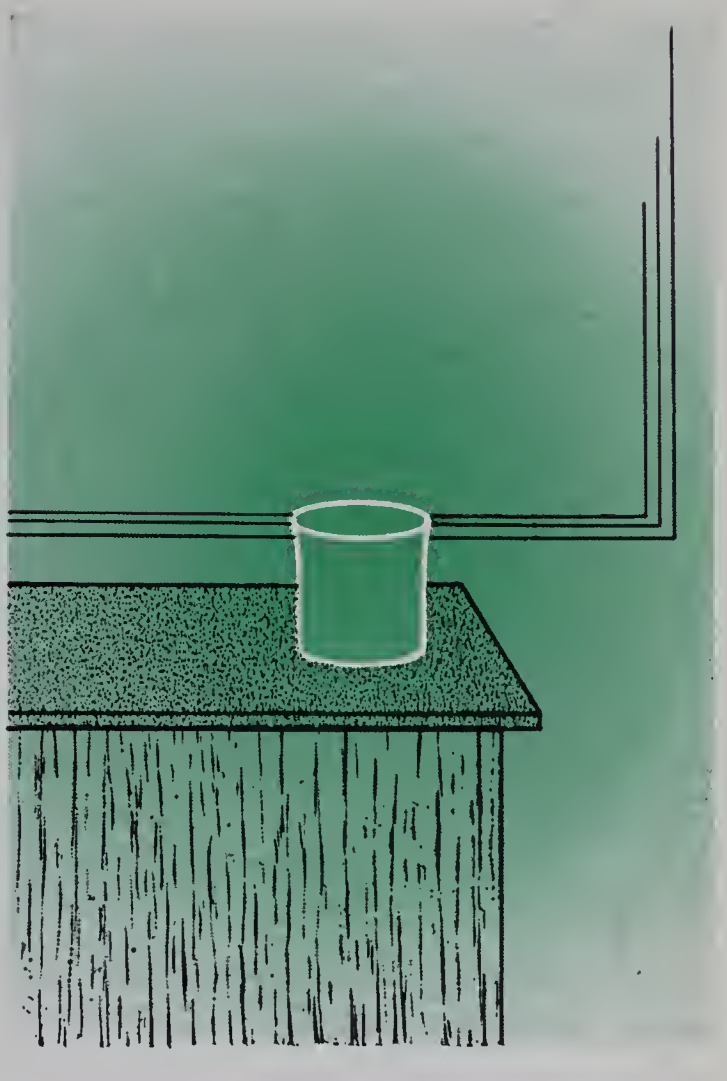
5-1 This diagram shows how molecules of a substance collide with one another in the process of diffusion.

forces over which the cell has no control. We refer to this passage as ***passive transport.*** Others involve energy within the cell. This is ***active transport.*** In addition, the penetration of some substances is regulated by the structure of the membrane itself.

Diffusion, the spreading of a substance by molecular motion. Let's visualize a substance as a mass of quivering molecules, bumping into one another like a crowd of people at a bargain counter. Molecules move in straight lines until they collide with other molecules, bounce off, and collide again. The force moving these molecules is internal kinetic energy rather than an outside force. Each molecule thus moves independently of other molecules. This molecular movement occurs in gases and liquids and to a lesser extent in solids. The force of collisions causes molecules to spread apart from one another and distribute equally in a given area. We refer to this molecular distribution as ***diffusion.***

To illustrate diffusion of gaseous molecules, let's imagine that you open a bottle of ether in the front of a closed room (Fig. 5–2). Ether molecules are *concentrated* inside the bottle. As soon as you open the bottle, they start diffusing into the air. Soon you begin to smell ether across the room. As diffusion continues, the ether odor becomes stronger. More and more ether molecules are mingling with the molecules of gases of the air. Finally, when all of the ether molecules are distributed equally among the air molecules, diffusion stops. A state of *equilibrium* has been reached.

According to the laws of diffusion, two things happened. Ether molecules diffused from the bottle into the air, and air molecules diffused into the ether bottle. Both movements were from a region of *greater* molecular concentration to one of *lesser* molecular concentration. This did not occur in a uniform flow of molecules, but in a random spreading out resulting from molecular collisions. Diffusion continued until the concentration of air and ether was equal in all areas of the room.



5-2 When a beaker of ether is uncovered in a tightly closed room, ether molecules mingle with molecules of the gases in the air. Eventually, molecules of ether and molecules of other gases are evenly distributed through all parts of the room.

Other familiar examples of diffusion. Solids and liquids, or liquids and other liquids, may diffuse as readily as gases *if they normally mix and do not repel each other.* Drop a cube of sugar into a glass of water. As the sugar dissolves taste the water from time to time. You will be able to taste the increase in the number of sugar molecules as diffusion occurs. Finally, the sugar will dissolve completely without any stirring. Sugar molecules diffused from a region of greater concentration (the lump) into a region of lesser concentration (the water). Meanwhile, water molecules diffused into the sugar. When equilibrium was reached, all parts of the solution tasted equally sweet.

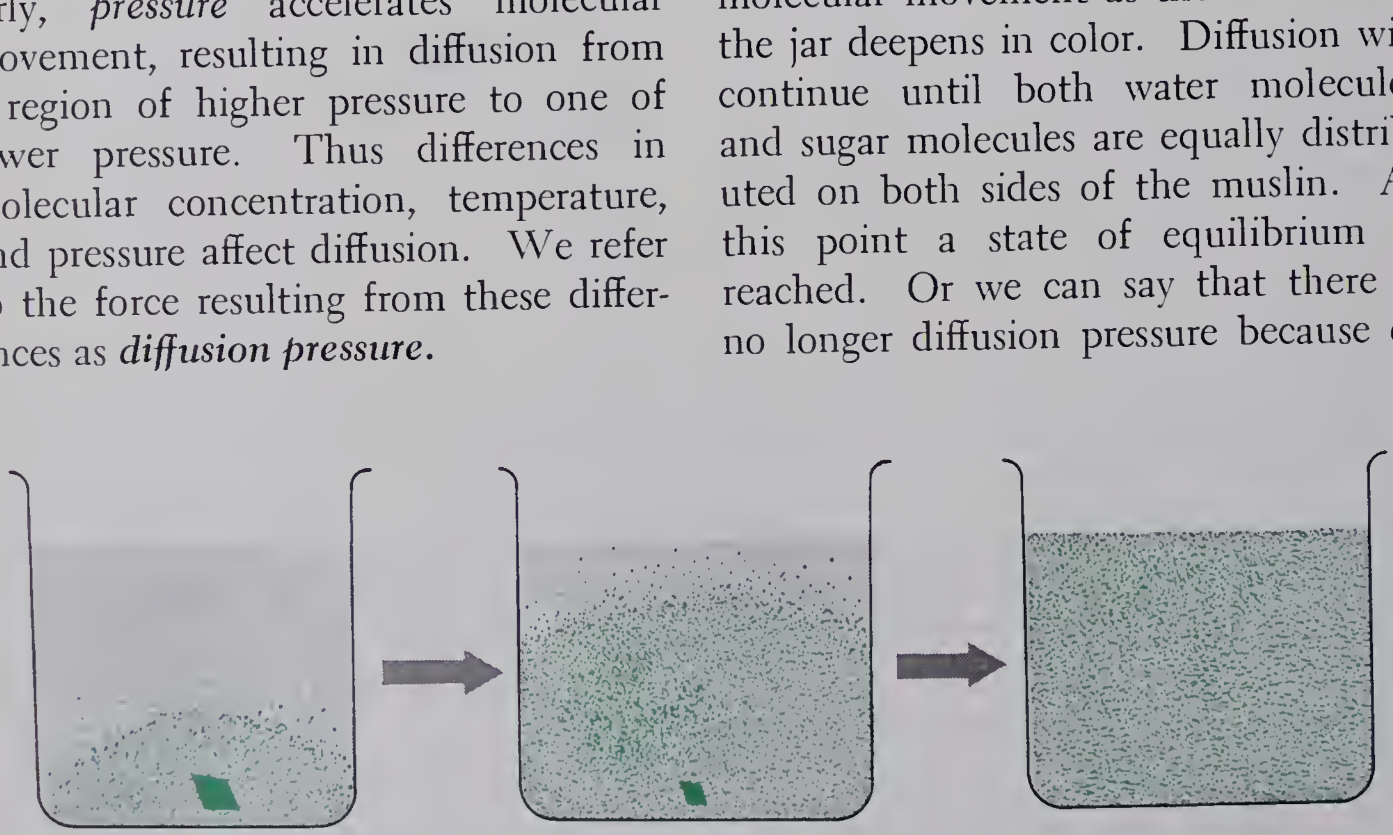
You can watch diffusion occur by dropping some crystals of potassium permanganate into a jar of water. Deep purple particles stream from the crystals into the water. The color of the solution deepens as diffusion progresses. Finally, the crystals disappear and the water solution is uniformly a deep purple color.

External factors that influence diffusion rates. In addition to molecular concentration, two other factors influence the rate at which diffusion occurs. One of these is *temperature*. The higher the temperature the greater the speed of molecular movement. Thus diffusion occurs from an area of higher temperature to one of lower temperature. Similarly, *pressure* accelerates molecular movement, resulting in diffusion from a region of higher pressure to one of lower pressure. Thus differences in molecular concentration, temperature, and pressure affect diffusion. We refer to the force resulting from these differences as ***diffusion pressure.***

Diffusion through a permeable membrane. How strong are the forces of diffusion? To what extent does a membrane interrupt or alter the movement of diffusing molecules? This, of course, depends on the nature of the membrane as well as the diffusing substances.

First we shall consider the case of diffusion through a permeable membrane. Fig. 5–4 shows a simple diffusion apparatus that you can easily set up in the laboratory. The lower bulb of a thistle tube is filled with a molasses solution (commercial molasses may be used). A piece of fine muslin is tied tightly over the open end of the bulb. The thistle tube is then fastened to a clamp (a ring stand may be used) and submerged in a jar of water.

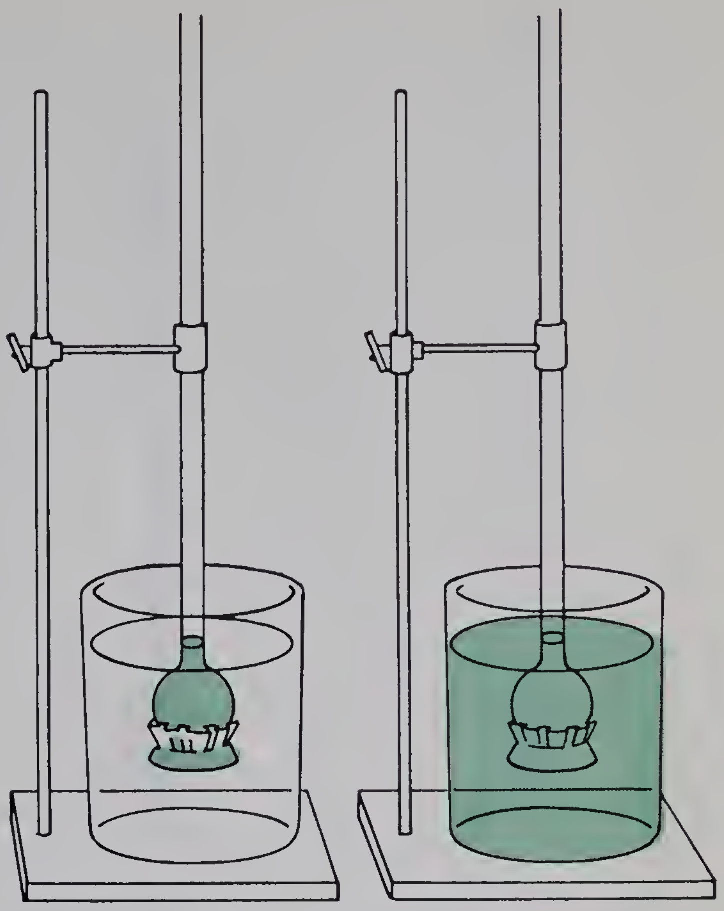
Since the muslin is permeable both to water molecules and to sugar molecules in the molasses, two things will happen. Water molecules will diffuse from the jar into the molasses in the thistle tube. At the same time sugar molecules will diffuse from the thistle tube into the jar. You can observe this molecular movement as the solution in the jar deepens in color. Diffusion will continue until both water molecules and sugar molecules are equally distributed on both sides of the muslin. At this point a state of equilibrium is reached. Or we can say that there is no longer diffusion pressure because of



5-3 Three stages in the diffusion of a solid into a liquid.

equal molecular distribution. What would happen to a cell if its membrane were permeable to this degree? It is true that water and molecules of other substances could enter readily. But wouldn't the cell's own molecules diffuse into the environment just as readily? Logically, a plasma membrane must be differentially permeable, allowing certain materials to enter but retaining the molecules of proteins and other substances composing the vital structures of the cell.

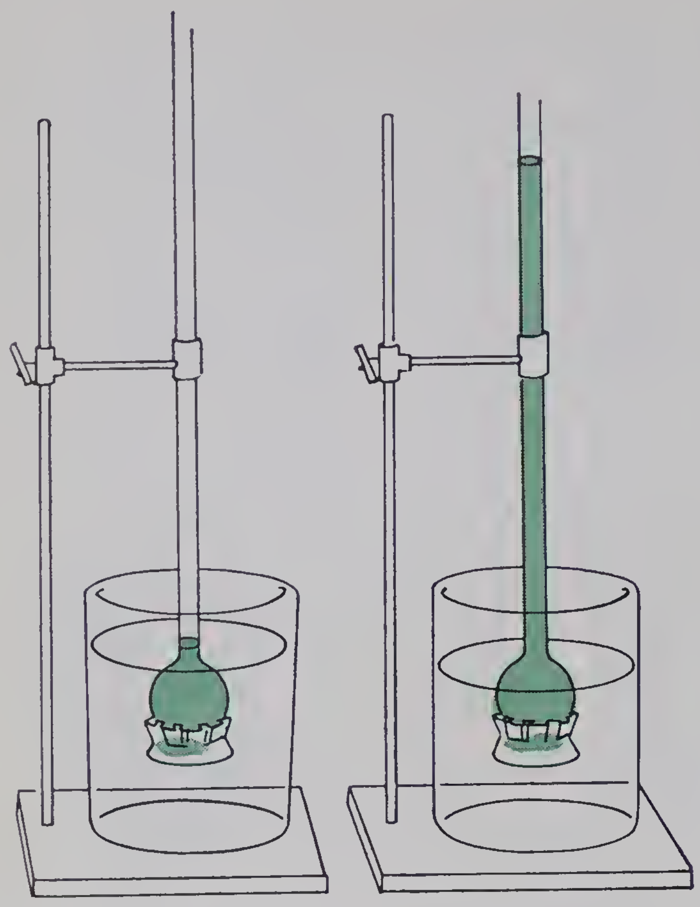
Diffusion through a differentially permeable membrane. A variation of the preceding experiment is shown in Fig. 5–5. The apparatus used is the same except that a differentially permeable membrane (sheep bladder may be used) is substituted for the muslin. In the classification of penetration rates of various molecules (page 72), you will recall that water molecules penetrate a differentially permeable membrane rapidly, while those of sucrose pass through very slowly. The molasses in the thistle tube is a concentrated sucrose solution. According to the laws of diffusion, water molecules should move through the membrane from the region of greater concentration in the jar to the region of lower concentration in the thistle tube. This movement occurs freely. However, the membrane permits but little diffusion of the more concentrated sucrose molecules in the thistle tube to the jar. Consequently there is uneven molecular diffusion. Over a period of time (usually several hours) the water level in the tube rises. However, as the solution rises in the tube, another force is involved. This is the force of gravity tending to pull the column downward. The weight of the solution in the thistle tube creates a pressure against the inner surface of the membrane. When this force is equal to the diffusion pressure of the water molecules, diffusion ceases.



5-4 Diffusion through a permeable membrane.

Osmosis – a diffusion of water. The experiment we have just described involved *the diffusion of water through a differentially permeable membrane from a region of greater concentration to a region of lesser concentration.* Biologists refer to this water diffusion as ***osmosis.*** In the definition of osmosis, *concentration* refers only to water molecules, not to substances dissolved in water.

As water diffuses into a cell by osmosis, it builds up a pressure, known as ***turgor*** (*ter*-ger) ***pressure.*** Since the plant cell is encased in a wall, it does not stretch or bulge as this internal pressure increases. Internal water pressure forces the plasma membrane and cytoplasm firmly against the wall, causing the cell to become stiff, or *turgid* (*ter*-jid). When turgor pressure, which would tend to force water molecules out



5-5 Diffusion through a differentially permeable membrane.

of the cell, becomes as great as the diffusion pressure which is causing them to diffuse into the cell, an equilibrium is reached. Diffusion stops.

Thin-walled plant tissues such as those composing leaves, flower petals, and soft stems maintain their stiffness by cell turgidity. As long as there is sufficient water supply in the cell environment, this internal turgor pressure is maintained. Otherwise the plant wilts.

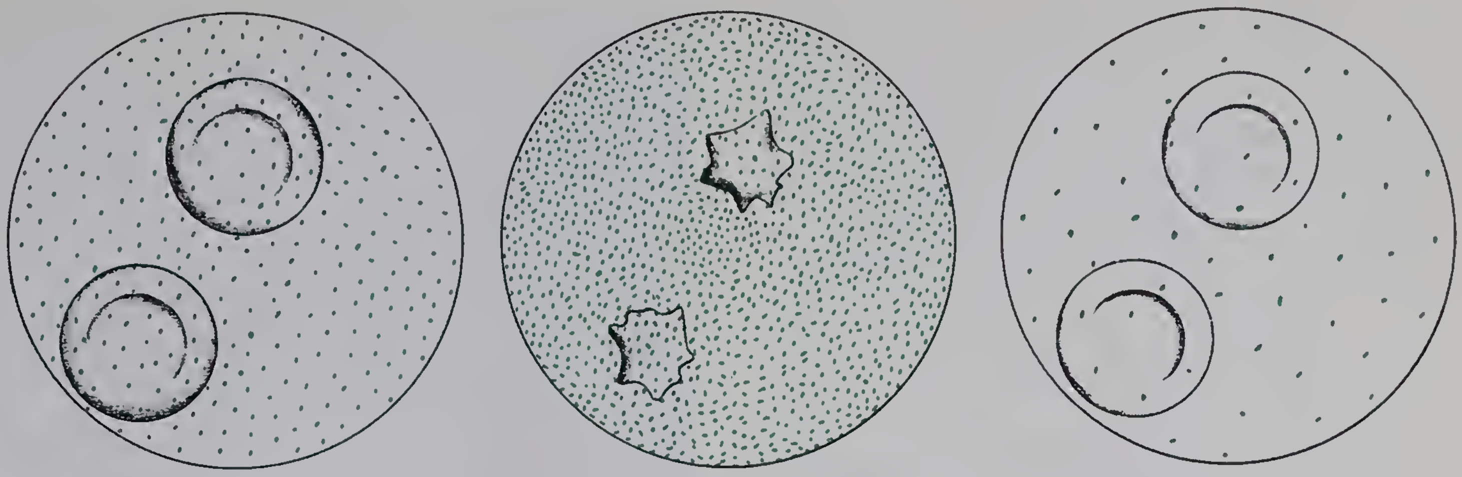
Water problems in animal cells. A plant cell builds up turgor pressure because its wall can withstand this internal force. However, an animal cell lacks this supporting structure and would burst if turgor pressure were built up. For this reason animal cells and tissues must have water-eliminating mechanisms.

Many one-celled organisms, living in a fresh-water environment, are equipped with special water-eliminating organelles known as ***contractile vacuoles.*** These tiny pumps work continuously, eliminating water through the membrane as rapidly as it diffuses into the cell. Were it not for these special structures, the cells would soon burst. Fish and other gill-breathing aquatic animals take in large amounts of water with the oxygen they absorb into the blood. In these animals excess water is excreted from the body in urine. Our kidneys, sweat glands, and lungs eliminate excess water and prevent our cells from receiving too much water.

You can observe the effects of excessive water absorption in animal cells by putting one-celled animals in distilled water. The diffusion pressure in distilled water is greater than these organisms can overcome by water-eliminating organelles. Soon the cells swell and burst. The presence of minerals and other soluble materials in pond water prevents this from happening in nature by reducing the diffusion pressure. Similarly, if you place a drop of blood in distilled water, the cells swell and burst almost immediately.

Plasmolysis, the loss of cell turgor. Remember that a cell has no control over the movement of water molecules through its plasma membrane. The direction in which water diffuses is determined by differences in the concentration of water inside and outside the cell. If a water solution outside the cell contains more dissolved substances and therefore has a lower concentration of water molecules than the solutions inside the cell, water will diffuse from the cell into its environment. This results in loss of turgor pressure and shrinking of the cell content. This condition is called ***plasmolysis*** (plaz-*mohl*-y-sis).

You can observe this water loss in several ways. Slice two pieces of potato, and place one in strong salt water



5-6 The effects of absorption on red blood cells. Left: cells in a normal salt solution; middle: in a strong solution; right: in a weak solution.

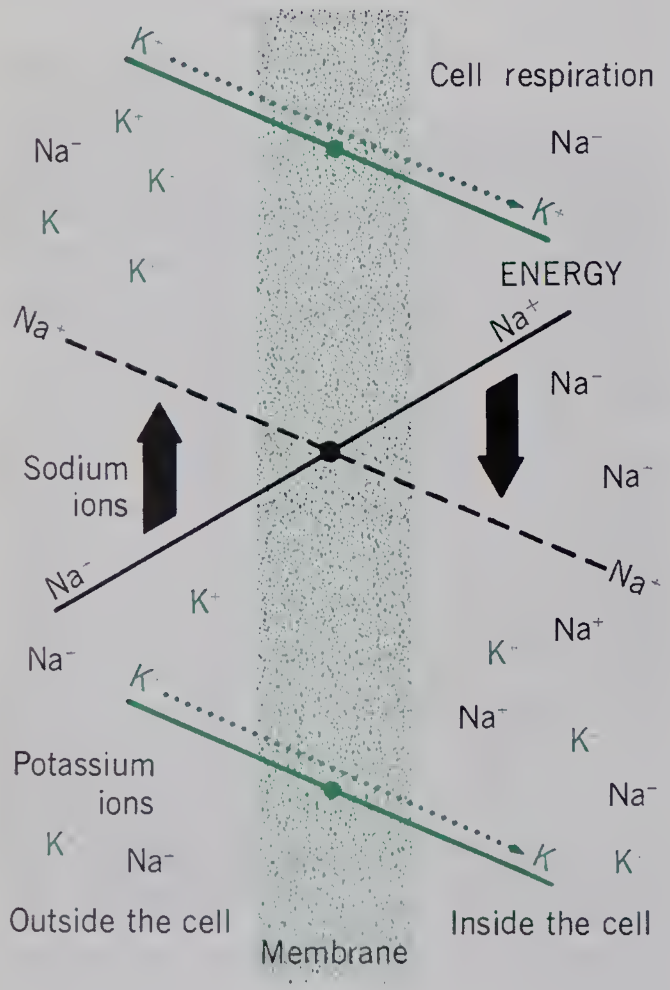
and the other in tap water. After 10 or 15 minutes, examine both slices. The slice in salt water will be limp, or *flaccid*, indicating that the cells have lost water and therefore turgor pressure. You can watch this process under the microscope as it occurs in a leaf of an aquatic plant like waterweed, *Elodea* (i-*lohd*-ee-a). Mount the leaf in water and notice that the cells are turgid. Then add one or two drops of strong salt solution at the edge of the cover glass. You will see the cell content shrink from the wall and collapse in a mass near the center. In animal cells, such as blood cells, the entire cell shrinks since there is no wall to give it firmness. Temporary plasmolysis may be corrected by the intake of water. But the cell will die if the condition continues very long. Now you can understand why salt kills grass and why shipwrecked men die from drinking salt water. Plasmolysis explains, also, why too heavy an application of strong fertilizers to the soil may kill the roots they contact.

Penetration of cell membranes by alcohol and other solvents. Alcohol, ether, and chloroform penetrate the plasma membrane and enter a cell even more rapidly than water. Biologists believe that these solvents dissolve the fat layer of the membrane and pass through quickly. These substances interfere with normal cell activities and have an anesthetic effect on cells. The rapid penetration of the membrane would explain why they act so quickly. The cell membrane is not permanently damaged, as other fat molecules move into the dissolved region.

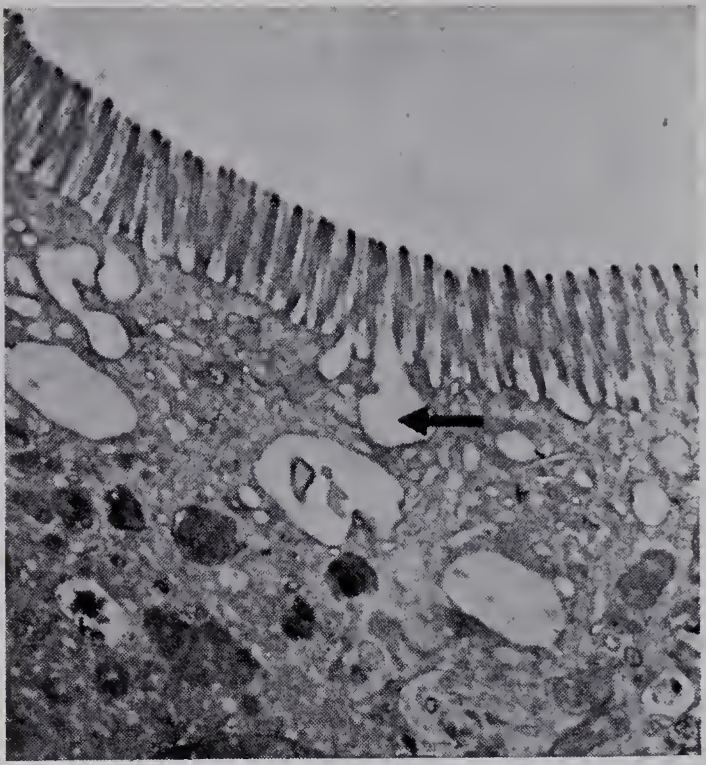
Diffusion of ions through a plasma membrane. Various mineral salts, acids, and bases form ionic solutions in water. These charged particles penetrate a plasma membrane very slowly. Biologists have made extensive studies of ion absorption by a cell and still have many unanswered questions. One possible explanation suggests that the membrane itself has an electrical charge and that this charge is usually negative. This would repel negatively charged ions, since like charges repel each other. Furthermore, the negative ions would be attracted to positive ions present in the solution outside the cell. This attraction may be strong enough to prevent many ions from penetrating the membrane. Nevertheless, some ions do penetrate the plasma membrane and are important in the chemical activities of the cell.

The principle of active transport. We know that many cells receive or excrete molecules against a diffusion pressure that would normally cause movement in the opposite direction. For example, a root cell may absorb mineral ions from soil solutions that contain fewer ions than the cell already contains. According to the laws of diffusion, ions should move from the cell into the soil water. Similarly, cells of certain algae living in the ocean absorb iodine compounds when the concentration of these substances within the cells is already much higher than that of sea water surrounding them.

It is obvious that some force other than diffusion accounts for this movement through the membrane. Biologists refer to this force as ***active transport.*** They know that cell energy is used in transporting these substances through the membrane, although they are not certain just how the energy is used. They have proved that cell energy is involved by measuring the oxygen intake and carbon dioxide release during active transport. If the solute concentration outside of the cell is greater than that of the cell content, solutes enter the cell by diffusion. However, if the solute concentration outside the cell is lower than that of the cell, the oxygen intake and energy release increases sharply. The cell is then using its energy in solute absorption. This is active transport, as opposed to passive transport, or membrane penetration by diffusion pressure alone.



5-7 Since there are fewer sodium ions outside the cell than inside, they must enter by active transport. Since there are more potassium ions on the outside, they enter by passive transport.



5-8 An electron micrograph showing the process of pinocytosis. (S. L. Clark, Jr.)

Entry of large molecules into a cell. So far we have discussed the penetration of a plasma membrane by water molecules, ions, and other materials which could pass through pores in the membrane. But what about larger molecules, such as amino acids, lipids, and even larger masses of material? These particles cannot pass through membrane pores, yet they are known to enter cells.

In the discussion of the structure of a plasma membrane, do you remember the reference to numerous infolding pockets? Biologists believe that large molecules and other particles flow into these indentations and are sealed off as the membrane closes behind them. The material is then enclosed in a membrane within the cell as a vacuole. This engulfing process is referred to as ***pinocytosis*** (pi-noh-cy-*toh*-sis). It is another important factor in cell absorption.

IN CONCLUSION

In order to survive, an organism must maintain a steady state in all its cells, even though conditions in the environment are constantly changing and may become unfavorable. This involves adjustment of the whole organism to external environmental conditions as well as adjustments of organs, tissues, and cells in its internal environment. We refer to these self-regulating devices as homeostasis.

Whether the environment of a cell will supply its chemical requirements for maintaining life activities or remove vital substances and destroy the cell depends on many factors. One of these is diffusion, a form of passive transport over which the cell has no control. Water normally enters a cell by osmosis, but may also leave the cell and lead to its destruction. But while the cell cannot overcome diffusion pressure in water movement, it does overcome this force in active transport. When active transport occurs, the cell uses its own energy to absorb minerals in amounts much greater than the concentration of these materials in the solutions outside the cell.

What happens to the many molecules and ions that penetrate the membrane and enter the cell substances? Some are building blocks used in molecular construction. Others are fuel for the cell powerhouses. We summarize the chemical activities involved in the growth, repair, and maintenance of the cell under the general heading of metabolism. We shall explore this next.

BIOLOGICALLY SPEAKING

active transport
contractile vacuole
differentially permeable
diffusion
diffusion pressure
homeostasis
osmosis
passive transport
permeable
pinocytosis
plasmolysis
turgor pressure

QUESTIONS FOR REVIEW

1. Define homeostasis and explain why homeostatic adjustments are necessary for the survival of an organism.
2. Give examples of homeostatic adjustments at various levels of organization of living things.
3. Distinguish between a permeable and a differentially permeable membrane.
4. Explain diffusion in terms of molecular movement.

5. Under what condition is a state of equilibrium reached?
6. How are temperature and pressure related to the rate of diffusion?
7. What is diffusion pressure?
8. Define osmosis.
9. What is turgor?
10. Would a cell build up turgor pressure if its membrane were permeable to all of the molecules it contacts? Explain.
11. Explain why animal cells do not build up turgor pressure.
12. Why do blood cells burst quickly if they are put in distilled water?
13. Describe several methods by which animal cells eliminate excess water.
14. Describe the cause of plasmolysis of a plant cell and the physical changes that occur.
15. Why do alcohol, ether, and chloroform penetrate a cell membrane rapidly?
16. What force exceeds diffusion pressure during active transport of minerals through a cell membrane?
17. Describe the entry of substances into a cell by pinocytosis.

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the homeostatic adjustments you have observed in organisms of your region.
2. It was once thought that the size of the pores in a cell membrane determined molecular penetration. Give evidence to show that this is not always true.
3. Why is it necessary that a cell have a higher solute concentration than the surrounding external solutions?
4. What might happen to the cells of a fresh-water plant if it were placed in salt water? Why would fresh water destroy a salt-water plant?
5. How have biologists demonstrated that active transport involves cell energy?

CHAPTER 6

CELL NUTRITION

The source of energy. Visualize a wrecking crew tearing out the interior of a building while a construction crew, working in the same rooms, is picking up the debris and building it up again. Such destructive and constructive processes occur simultaneously in a living cell. Complex molecules are built up in some processes and broken down in others. Why all of this seemingly wasteful activity? Cells must have energy every second of their existence. This energy comes from the chemical bonds of complex molecules. It is necessary to break these molecules down to set the energy free. Where will the next energy come from? From other fuel molecules, of course. Does the cell build up these molecules? Some cells can, but many cannot. Thus you can see that some cells are "self-fueling," while others depend on other cells.

These tearing down and building up processes apply to substances that form the cell as well as to fuel molecules. Cell structures are constantly changing. Cell parts wear out and must be replaced. Growth and repair is a continuous process in a living cell. Where does the cell get the molecules necessary to form its own substances? Again, some are products of the cell's own chemical activities, while others are received from the environment.

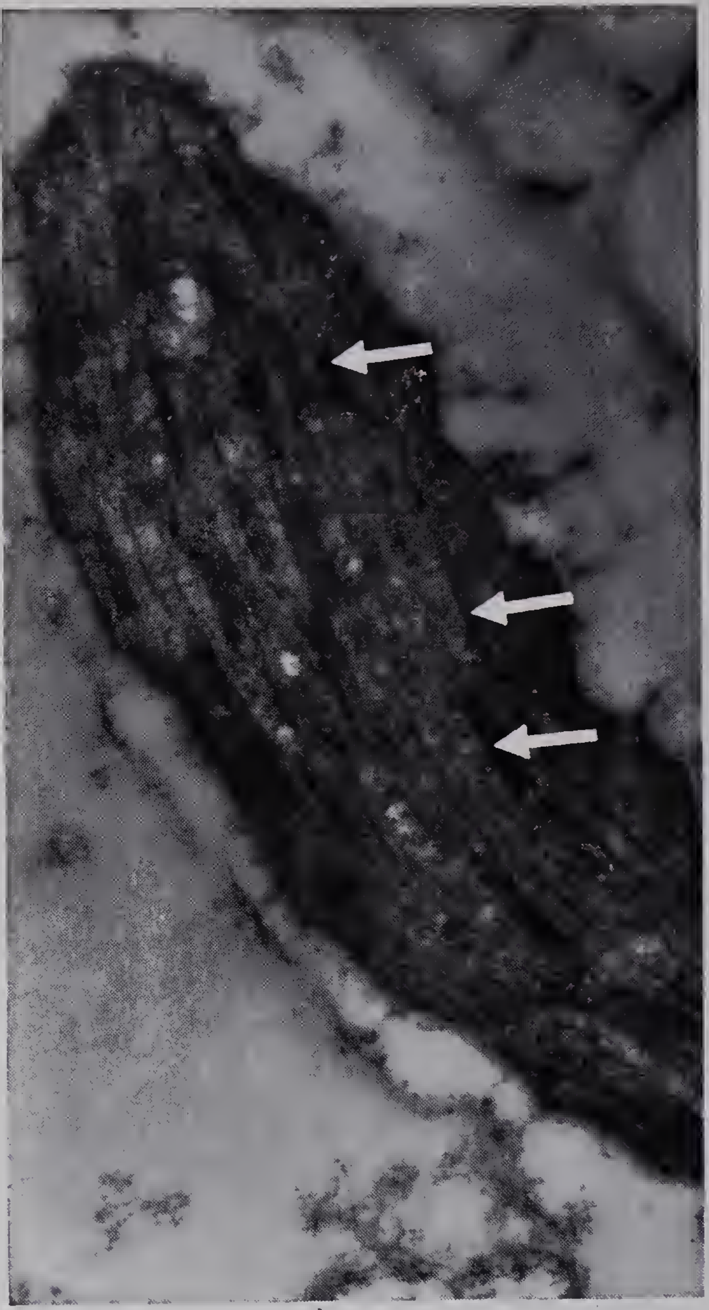
Energy to maintain life activities. In our study of cell processes we must consider not only cells but the larger structures they form and, of course, entire organisms. Let us imagine that we can completely enclose an entire community, perhaps several square miles in area, and prevent any organisms or materials from entering or leaving the closed environment. We will include wooded areas, farms, open fields, and ponds in the gigantic enclosure. Animal life native to the region as well as domestic animals will also be included, along with the people who live there. In other words, life would continue normally, except that the whole region would be isolated from the outside world. Could this isolated society continue? Plants and animals would live and die. Their chemical remains would supply the requirements of new generations. Matter would be used and re-used, organized in complex substances and broken down to simpler form, in a continuous cycle year after year and generation after generation.

Now suppose we covered this giant enclosure and shut out all of the light. Do you think life could continue as before? You have probably concluded that the people, the animals, and even the green plants would be doomed. Life might continue until all the food was consumed; then all would perish. The matter could still cycle, but what about the energy necessary to build food molecules and support life? Can the heat energy released in living cells be trapped and reused? Can the plants and animals capture the energy used in their own activities? No, *energy does not cycle.* When we shut out the light, we cut off the supply of new energy which must enter the living world constantly.

What if we removed all the green plants and left the animals and non-green plants, such as fungi, in full light? Would life continue? No, the animals would be as helpless as though there were no light. They would have energy all around, but none in the form they could use to supply their cells. Doesn't this place the cells of green plants in a unique position in the world of life? Marvelous, indeed, must be the chemical processes of plant cells that capture sunlight and store chemical energy in the molecules that fuel the cells of living things.

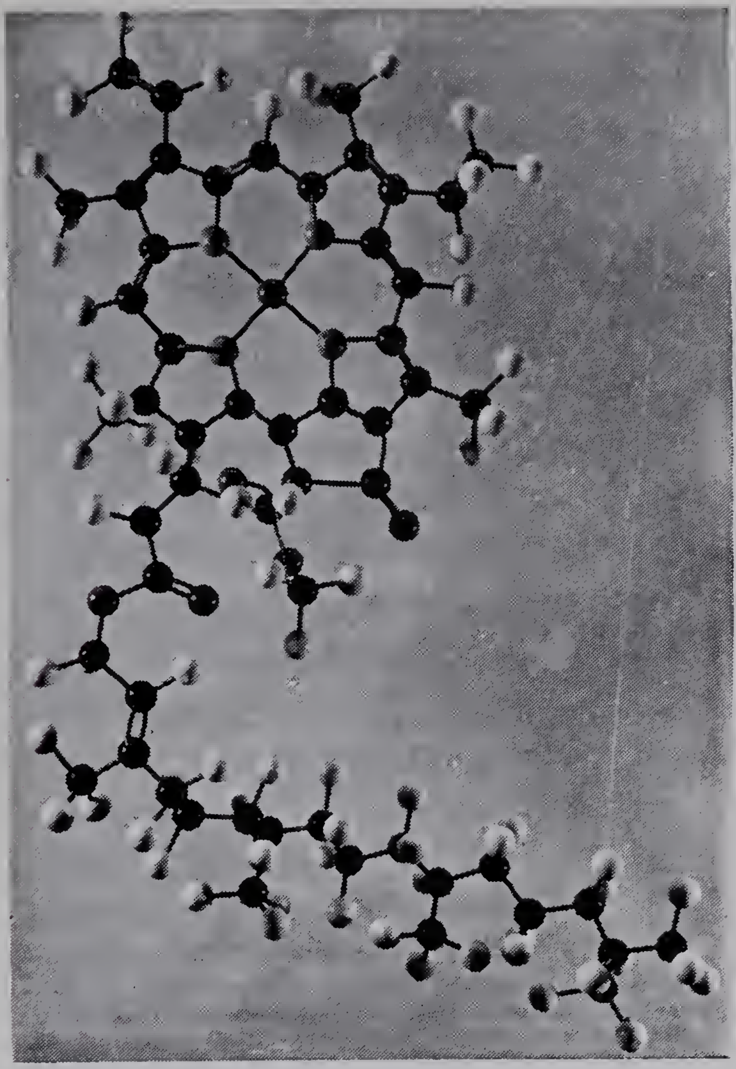
A marvel of plant life. To explore the machinery of the cell and the process in which fuel molecules are organized, we can select almost any plant part as long as it is green. We might choose a leaf cell, a cell from a green stem, or a hairlike strand of an alga growing in a pond. Any of the seaweeds could be used, for while they may be brown or red in color, they also contain chlorophylls.

The process we are exploring is known as ***photosynthesis.*** The name nearly defines the process, for *photo* refers to light, while *synthesis* means the building of a complex substance from simpler substances. The simpler substances are *carbon dioxide* and *water,* while the complex substance is *glucose.* You may have already concluded that light is necessary for photosynthesis and that some of the light energy is somehow captured in the sugar molecules. But how is this accomplished? Certainly, carbon dioxide and water will not form glucose in a flask set in sunlight.

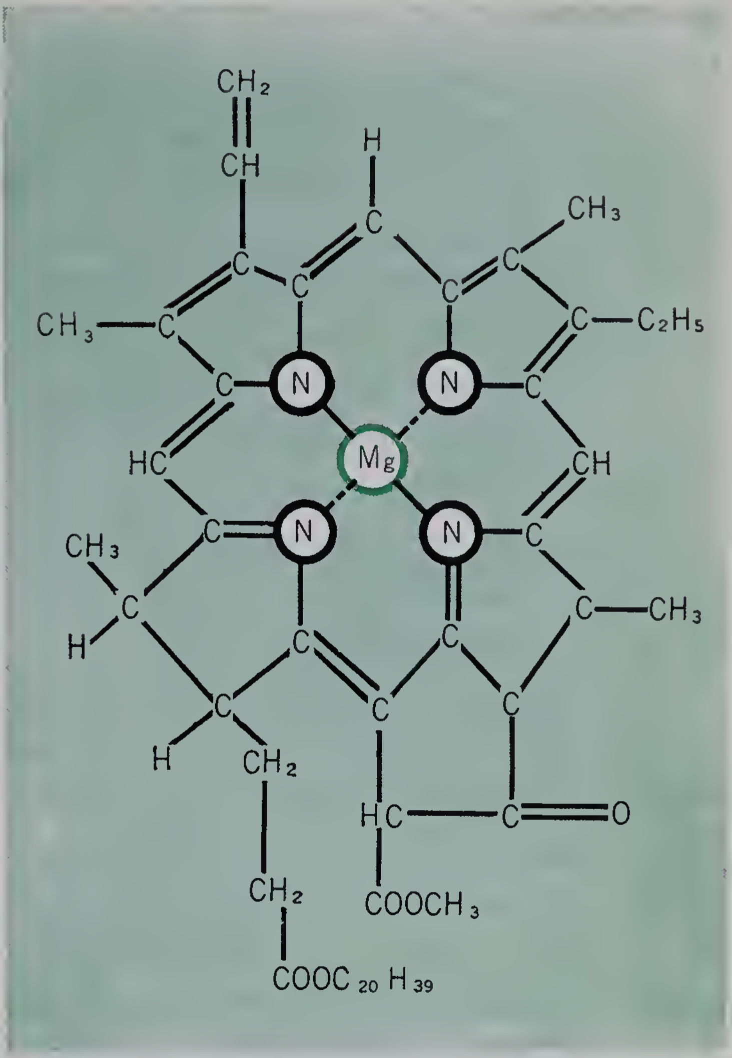


6-1 This micrograph of a chloroplast shows a magnification of 15,000 times by an electron microscope. Arrows point to the grana. (Martin Co. — RIAS)

Chloroplasts, the machinery of photosynthesis. In our discussion of the parts of a cell, we referred to cytoplasmic inclusions known as *chloroplasts* (*klor*-oh-plasts). Do you remember that they are made up of stacks of cylindrical disk-shaped protein bodies held together by layers of fatlike molecules? These are the *grana.*



6-2 A model of the chlorophyll *a* molecule. (Harvard University News Office)



6-3 The structural formula of the chlorophyll *a* molecule.

While we often speak of chloroplasts as the machinery of photosynthesis, certain cells that carry on the process have no organized chloroplasts. Such primitive cells are found in the blue-green algae. However, the electron microscope reveals that even these cells have grana. They are dispersed through the cytoplasm rather than confined to organized chloroplasts. Perhaps we should say, then, that grana rather than chloroplasts constitute the machinery of photosynthesis.

Chlorophyll, the agent of photosynthesis. If bean or corn seedlings are grown in total darkness, the leaves will be yellow rather than green because light is necessary to produce the ***chlorophylls.*** If such a plant is moved to a light place, photosynthesis will not occur until chlorophyll has formed in its leaves. Chlorophyll, then, is essential for photosynthesis.

Chlorophyll molecules are embedded partially in the protein disks of the grana and partially in the fatlike layers between them. Frequently molecules of different forms of chlorophyll are mixed in the grana. Four different types of chlorophyll are found in various plant cells. The most abundant form, and the most important in photosynthesis, is chlorophyll *a*. This bright bluish-green pigment has molecules containing carbon, hydrogen, oxygen, nitrogen, and a single atom of magnesium that lies in the center of the molecule. The chemical formula for chlorophyll *a* is $C_{55}H_{72}O_5N_4Mg$. A second yellowish-green pigment is referred to as chlorophyll *b*. Its chemical formula, $C_{55}H_{70}O_6N_4Mg$, shows that it differs from chlorophyll *a* only in the number of hydrogen and oxygen atoms present in the molecule. Small amounts of iron compounds are necessary for the formation of chlorophylls, although iron atoms do not enter into their molecular structure.

Chloroplasts in the cells of seed plants usually contain both of these chlorophylls in the approximate ratio of three parts of chlorophyll *a* to one part of chlorophyll *b*. Certain other plants, more primitive than seed plants, contain other chlorophylls. Brown algae contain chlorophyll *a* and chlorophyll *c*, while red algae contain chlorophyll *a* and chlorophyll *d*. The purple sulfur bacteria have a unique form of chlorophyll, known as *bacteriochlorophyll*, contained in granules rather than grana. These bacteria are exceptional in that they are capable of photosynthesis.

Chlorophyll *a* is necessary for photosynthesis, and yet it does not enter into the process chemically. Remember that we refer to such an accelerator of a chemical reaction as a *catalyst*. Other chlorophylls may assist the process by absorbing light energy and transferring it to chlorophyll *a*. Other pigments in the chloroplasts, including xanthophylls and carotenes, may also transfer energy to chlorophyll *a*.

You can remove chlorophyll from cells by heating a plant part such as a leaf in alcohol or some other solvent. You might even assume that you could use this catalyst in the laboratory and carry on photosynthesis artificially. Chloroplasts have been removed from cells and, under these conditions, have retained their photosynthetic abilities. But chlorophyll alone cannot produce a carbohydrate. Thus photosynthesis seems to be limited to the processes of a living cell, or at least to the grana of the chloroplasts.

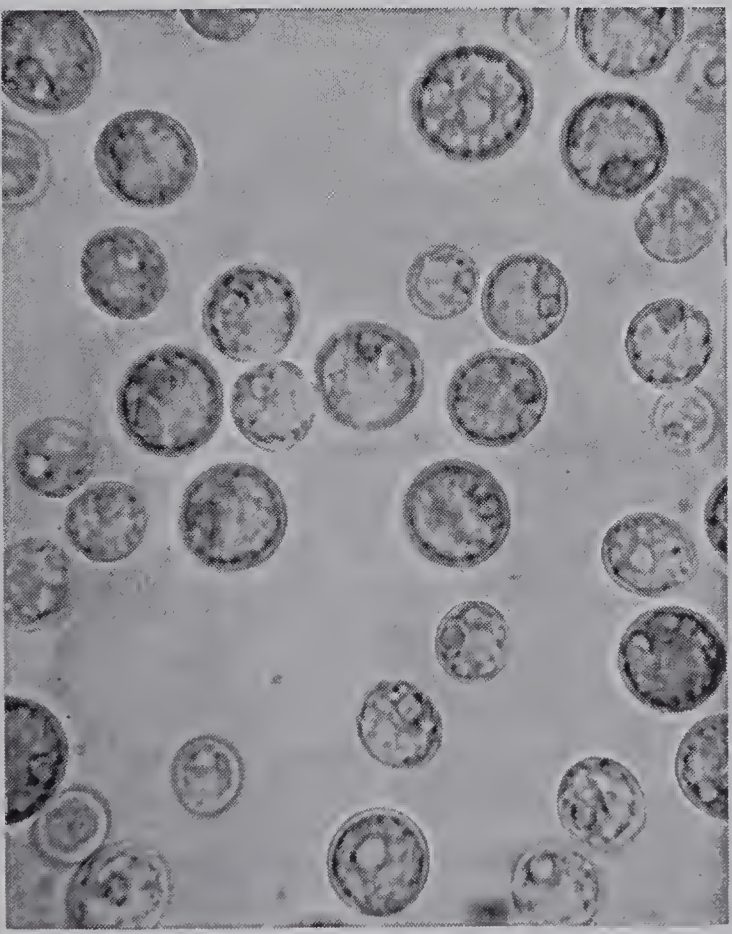
In addition to chlorophyll, chloroplasts contain *enzymes* which are essential to photosynthesis. Enzymes also serve as catalysts and, together with chlorophyll, cause the chemical reactions involved in the various steps of photosynthesis to occur, without being changed or used up in the processes.

The general nature of photosynthesis. Biologists have had a general understanding of photosynthesis for many years. They assumed, however, that it was a single chemical reaction in which carbon dioxide and water were combined in a cell to form a glucose molecule. Oxygen was known to be a by-product of the process. Chlorophyll has long been recognized as a catalytic agent of the process, although its actual role was not really understood until recent years. Biologists have known, too, that light energy is absorbed during the process and that, somehow, it is locked in the bonds of glucose molecules. The overall, simplified chemical equation for photosynthesis is commonly written:

$$6\,CO_2 + 6\,H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6\,O_2$$

This equation, while it accounts for the materials required and the products formed in the process, fails to summarize the true nature of photosynthesis. Is photosynthesis a single reaction as the equation indicates? Does carbon dioxide react with water directly to form glucose? Does the oxygen released as a by-product come from the carbon dioxide, the water, or both? How is light energy transformed to chemical energy in glucose molecules? How is chlorophyll related to the process? These questions biologists asked for years. Only recently have they begun to solve the mystery of the most important chemical process in the world.

Tools to explore the nature of photosynthesis. By 1941 biologists and chemists had been provided with a new and effective tool for chemical research. Isotopes were available from atomic reactors in research centers. Among the available isotopes were oxygen–18 (O^{18}) and carbon–14 (C^{14}), both heavy forms of the elements. These could be traced through chemical reactions as tagged atoms, provided the reactions could be stopped at a given instant so that products formed could be isolated and analyzed. The problem now was to find a suitable plant which could be killed and analyzed quickly. It would be difficult to kill leaf cells instantly and remove the products of photosynthesis at various stages. But a tiny, fast-growing alga, known to the biologist as *Chlorella* (klo-*rel*-a), proved to be a perfect subject. This microscopic one-celled alga can be killed quickly for extraction of the intermediate products which are formed, then changed almost instantly during photosynthesis. We owe much to this tiny plant, for it yielded one of the most significant biological discoveries of our age — the answer to the riddle of photosynthesis. It is interesting, too, that *Chlorella* is becoming important in two other areas. Tanks of this alga may accompany a spaceman on a journey to the moon or another planet. Why would photosynthesis be an important process in the closed environment of a space capsule? *Chlorella* is also being cultured experimentally in large quantities, with a possible view to using it as food for livestock or even for man.



6-4 *Chlorella,* a tiny alga, has contributed vastly to our knowledge of photosynthesis. (Robert W. Krauss)

The secret of photosynthesis unlocked. The first major discovery in the recent investigations of photosynthesis concerned the fate of water molecules in the process. Remember that biologists had not been able to determine whether oxygen came from water or carbon dioxide. Oxygen–18 provided the first answer. When *Chlorella* cells were grown in water containing heavy oxygen (H_2O^{18}), a remarkable discovery was made. The oxygen streaming from the *Chlorella* cells was heavy! Furthermore, glucose extracted from the cells contained no heavy oxygen. It was evident that, somewhere in the process, water molecules were split. This process requires a great amount of energy. It can be done electrically by means of an electrolysis apparatus. But here were tiny algae splitting water molecules in the grana of their chloroplasts. Where could this energy be coming from? Since light is necessary for the process, it was the logical energy source. Biologists had known that light provides the energy stored in glucose molecules, but

6-5 A simple technique for finding the relationship between light intensity and the rate of photosynthesis. Simply count the bubbles of oxygen that are released by submerged water plants under intense light. (Richard F. Trump)

that light energy splits water molecules was an entirely new concept. Chlorophyll plays an important part in this energy transfer. Thus, water molecules, light energy, and chlorophyll molecules are involved in the first stage, or ***light reaction,*** of photosynthesis.

The splitting of water molecules in the light reaction is only the first stage in glucose production. What happens to the carbon dioxide? Carbon–14 provided this answer, at least in part. The use of $C^{14}O_2$ in controlled photosynthesis led to the discovery of the ***dark reaction,*** the second stage of the process. During this stage carbon is fixed in a series of chemical reactions, none of which requires light. In the path of carbon from inorganic carbon dioxide to organic glucose, many steps are involved and several intermediate products are formed. During these changes carbon atoms are bonded to form chains. Many other atoms may be joined to these chains to form an almost endless number of organic compounds.

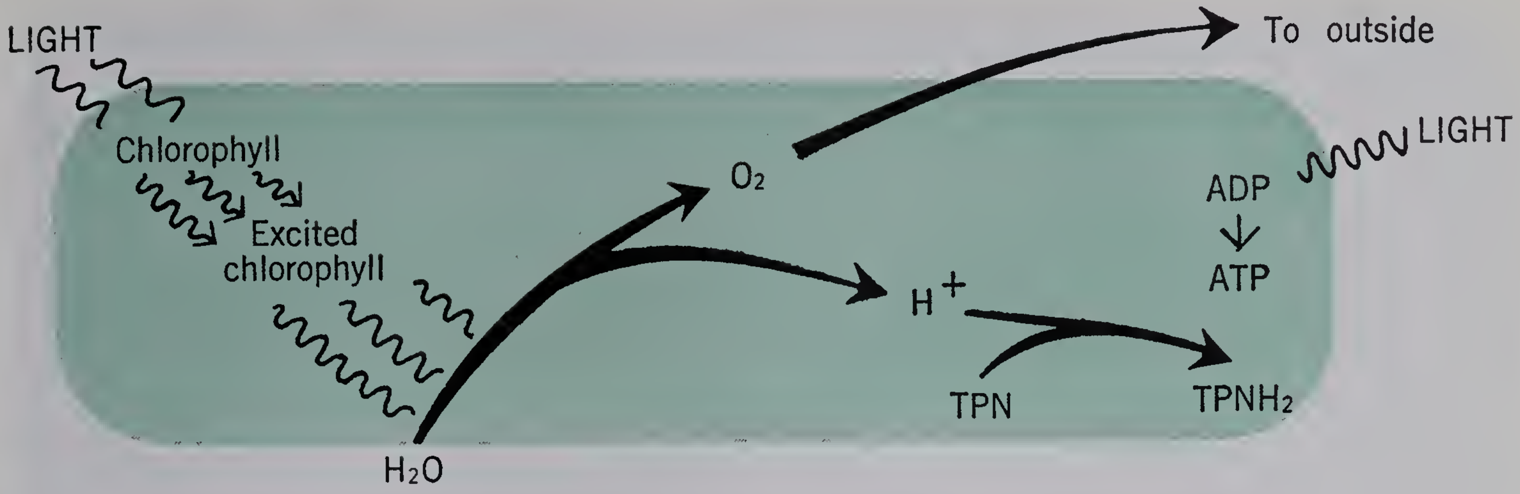
We may summarize the overall chemical changes that occur during both the light and dark reactions in photosynthesis in the equation:

$$6\,CO_2 + 12\,H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6\,H_2O + 6O_2$$

Heavy oxygen, as it was used in research in photosynthesis, is shown in green. Notice that the six molecules of oxygen ($6O_2$) released as a by-product result from the splitting of water molecules. The oxygen in the glucose comes from carbon dioxide. Notice, too, that water enters into the reaction and that it is a product as well. However, the water used in the process has *no relation* to the water produced.

While this equation represents the overall photosynthetic reaction as we understand it today, we must examine both the light and dark reactions more thoroughly to appreciate what occurs.

The light reaction, or photo phase. The first stage of photosynthesis, sometimes referred to as the *photo phase,* occurs only in the light and requires chlorophyll *a.* Thus it is obvious that light energy enters into reactions during the photo phase. As we describe the various activities of the light reaction, it might seem that it is a lengthy series of processes. Actually, this phase of photosynthesis occurs in a split second, perhaps in as short a time as 1/100,000 of a second! But we can best describe the various reactions that take place during the splitting of water molecules by light energy, or *photolysis,* as though they were steps, even though they occur almost simultaneously.



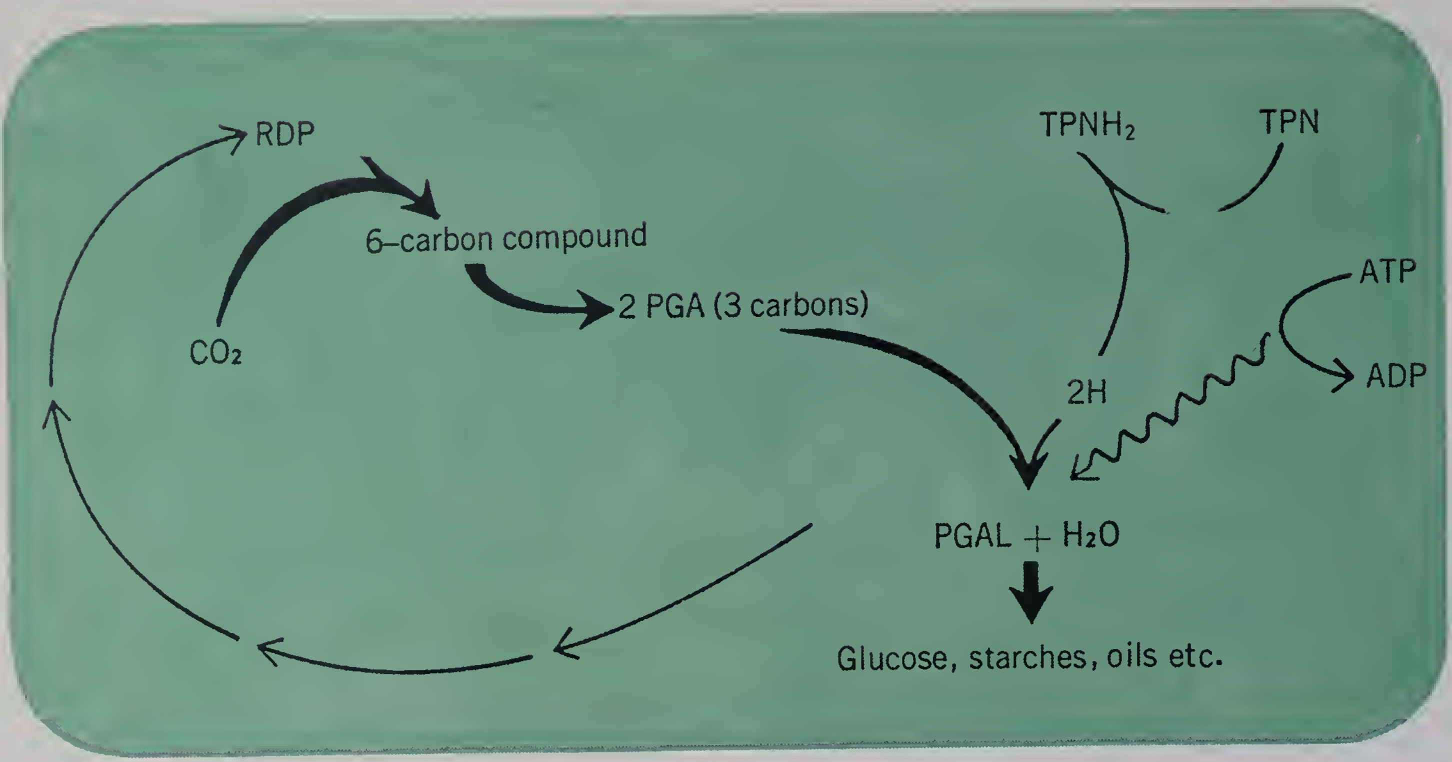
6-6 This drawing summarizes the light reaction of photosynthesis.

Chlorophyll is energized. As chlorophyll molecules lying along the grana of chloroplasts receive light energy, it is believed that a sudden change occurs in the molecules themselves. Electrons move to shells farther away from their nuclei, and consequently from lower to higher energy levels. The chlorophyll molecules are now energized, or excited. Absorption of energy by chlorophyll molecules transforms kinetic light energy to potential chemical energy. Thus chlorophyll functions as an ***energy carrier*** in the photo phase. Energy remains in the chlorophyll as long as the molecules remain in this excited condition. When this energy is released the electrons drop back to lower energy levels. The chlorophyll is no longer energized, but may be illuminated again and trap more light energy.

Water molecules are split. Energy released from energized chlorophyll supplies the force necessary to pry the atoms in water molecules apart. As we stated earlier, hydrogen atoms are joined to oxygen by very strong bonds in a water molecule. Just how these bonds are broken and stable water molecules are split is still an unanswered question. However, we do know that the process requires a great amount of energy, supplied by energized chlorophyll.

Additional energy is trapped in ATP. The photo phase of photosynthesis involves another important energy transfer necessary to support later chemical reactions. Chloroplasts contain a compound known as ***ADP*** (adenosine diphosphate). In addition they contain phosphate groups which can be added to ADP to form a higher energy compound known as ***ATP*** (adenosine [a-*den*-oh-seen] triphosphate). Part of the energy released from energized chlorophyll is used in this process. Thus, ATP is a second energy carrier in photosynthesis. Energy remains in the molecule as long as the extra phosphate group is attached. Chemical removal of the phosphate releases the energy and reforms ADP. It then receives energy and repeats the transfer process.

Hydrogen is trapped by TPN. As hydrogen is released during the splitting of water molecules in the light reaction, it must be captured immediately to prevent it from escaping from the cell or recombining with oxygen to form water. This is accomplished by a coenzyme referred to as TPN (*triphosphopyridine nucleotide*). We speak of TPN as a ***hydrogen acceptor*** because it combines readily with hydrogen to form $TPNH_2$. This acceptance is on a "loan basis," however, for the hydrogen is soon passed to another compound.



6-7 This drawing summarizes the dark reaction of photosynthesis.

The oxygen released when water molecules are split during the light reaction escapes from the cell as a by-product.

The dark reaction, or synthetic phase. The transfer of energy from chlorophyll to ATP during the light reaction "charges" the chloroplast for reactions to follow. With chemical energy available, these activities do not require light and are thus referred to as the dark reaction. But this does not imply that the dark reaction must occur in darkness. Actually, it occurs in the light and accompanies the light reaction.

We can summarize the most important result of the dark reaction as the fixing of carbon in a carbohydrate. This process occurs in several steps which form a cycle. Compounds are formed, broken down, and formed again. In this chemical activity, carbon atoms form chains to which atoms of hydrogen and oxygen may be joined by chemical bonds to form carbohydrate molecules. In this way the organic chemical world originates. We can summarize reactions in this stage of photosynthesis as follows:

Carbon dioxide is fixed by RDP. Chloroplasts contain a 5-carbon sugar phosphate known as RDP (*ribulose diphosphate*). This compound is composed of a 5-carbon sugar molecule to which two phosphate groups are attached. Within a fraction of a second after carbon dioxide reaches a chloroplast, it is fixed in a chemical compound by combining with RDP. Thus RDP serves as the highly important ***carbon dioxide acceptor.*** The immediate product of this reaction is a 6-carbon sugar which is very unstable and splits quickly into two molecules of PGA (*phosphoglyceric acid*). PGA is thus the first stable product of photosynthesis.

PGA is converted to PGAL. Within a fraction of a second PGA combines with hydrogen, supplied by $TPNH_2$. The products of this reaction are PGAL (*phosphoglyceraldehyde*), also known as triose phosphate, and water. This reaction requires a large amount of energy, since PGA is a low energy compound while PGAL has a high energy level. This energy is supplied from ATP by the removal of a phosphate group, converting it to ADP. PGAL can be used directly by a cell and for this reason might be considered to be the principal product of photosynthesis. While a cell does make immediate use of PGAL, much of it is converted to other products for transport from the cell or for storage. We will summarize several of these changes involved in the destiny of PGAL.

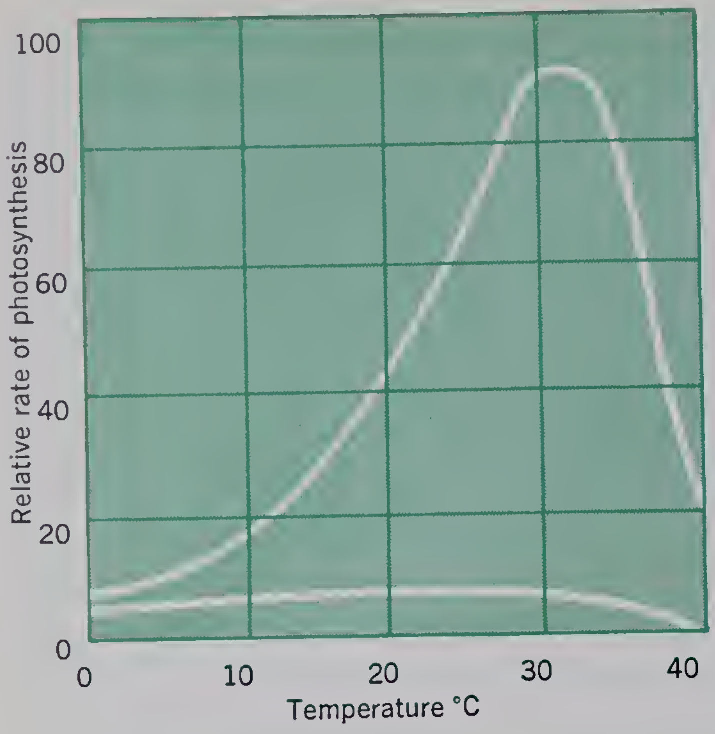
The destiny of PGAL. Since molecules of PGAL contain 3-carbon chains, PGAL may be used directly by a plant cell as a nutrient. In fact, plants nourished artificially with PGAL can survive without photosynthesis or any outside source of organic nutrients. However, a cell produces far more PGAL during photosynthesis than it needs, and much of the PGAL is changed to other products in further chemical reactions.

One essential product of PGAL is additional RDP to refuel the cell for further photosynthesis. You will recall that this 5-carbon sugar phosphate was present in the chloroplast and served as the carbon dioxide acceptor. You can see now how chemical reactions of the dark phase of photosynthesis constitute cycles. RDP was necessary to form PGAL. Part of the PGAL is converted back to RDP to prepare the chloroplasts for the next round.

Other molecules of PGAL are converted to glucose. This is accomplished by the combination of two molecules of PGAL, the removal of the phosphate group from each molecule, and the substitution of a hydrogen atom for each phosphate group. The formula for PGAL is $C_3H_5O_3$–(P). The attached phosphate is indicated in the parentheses. You can see how the combination of two PGAL molecules and the substitution of hydrogen for each would produce a glucose molecule ($C_6H_{12}O_6$).

Fructose, another monosaccharide with the same chemical formula as glucose, may also be produced from PGAL. Sucrose, a disaccharide with the chemical formula $C_{12}H_{22}O_{11}$, may then be formed by the combination of a fructose molecule and a glucose molecule and the removal of a molecule of water. Two glucose molecules may be combined and one water molecule removed to form maltose, another familiar disaccharide. Hexose sugar molecules ($C_6H_{12}O_6$) may also be joined in chains to form starches and cellulose. Some plants build PGAL molecules into various oils, such as corn oil, linseed oil, castor oil, and olive oil. Thus you can see that this important product of photosynthesis is the basis for a wide variety of products.

Conditions for photosynthesis. Since light is the energy source for photosynthesis, you would expect light conditions to have a vital relationship to the process. As you know, sunlight is composed of light rays of varying wavelengths and energy. The various rays making up sunlight — those producing red, orange, yellow, green, blue, and violet colors — are what we see in a rainbow. Together they are called the *visible spectrum.* Red rays have the longest wavelength and the least energy of the visible radiations. Violet rays, at the opposite end of the spectrum, have the shortest wavelength and the highest energy. Chloroplasts absorb these rays in varying amounts. Furthermore, plants vary in the rays they absorb. Most land plants absorb their greatest amount of energy from violet and blue rays and a somewhat smaller amount of energy from red and orange rays. While



6-8 The effect of temperature on photosynthesis. The upper curve represents high light, the lower low light.

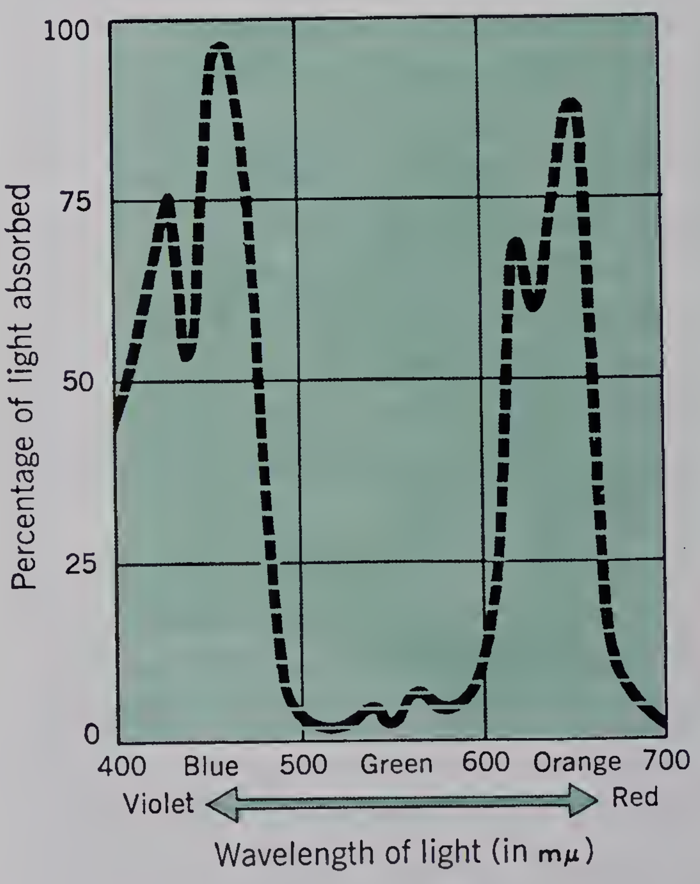
some of the green and yellow light is absorbed, much is reflected. Since only reflected light rays are visible, this accounts for the green or greenish-yellow color of chloroplasts.

Plants such as algae growing in the ocean have different light problems. Sea water absorbs most of the red and violet rays, in addition to reducing the total intensity of light. Much of the energy for photosynthesis in plants of the more shallow waters comes from the blue, green, and yellow portions of the spectrum. Deep-water algae, living at depths of 50 to 200 feet or more, receive most of their light energy from green and blue rays.

Temperature also influences the rate of photosynthesis, but not as much as you might expect. There is, however, a relationship between temperature and the carbon dioxide supply and the rate of photosynthesis. Plants growing in the normal atmosphere, with a carbon dioxide content of about 0.04 percent by volume, carry on photosynthesis most rapidly at a temperature of about 21° C. But if the carbon dioxide content is raised to 1.25 percent, photosynthesis occurs most rapidly at a temperature of about 30° C. Temperature probably varies the activity of enzymes involved in various steps of photosynthesis. However, temperature variations within the normal range during a plant growing season seem to have little effect on enzyme action until temperatures exceed about 32° C. From this point on, increase in temperature seems to reduce the rate of photosynthesis.

Water supply is another factor that influences the rate of photosynthesis. Water shortage affects the entire physiology of the cell and therefore reduces the rate of photosynthesis.

Biological significance of photosynthesis. Were it not for photosynthesis the life of our earth would probably be limited to a few bacteria. There would be no forests or grasslands. Certainly there would be no animal populations. What makes the process so vital to life? It

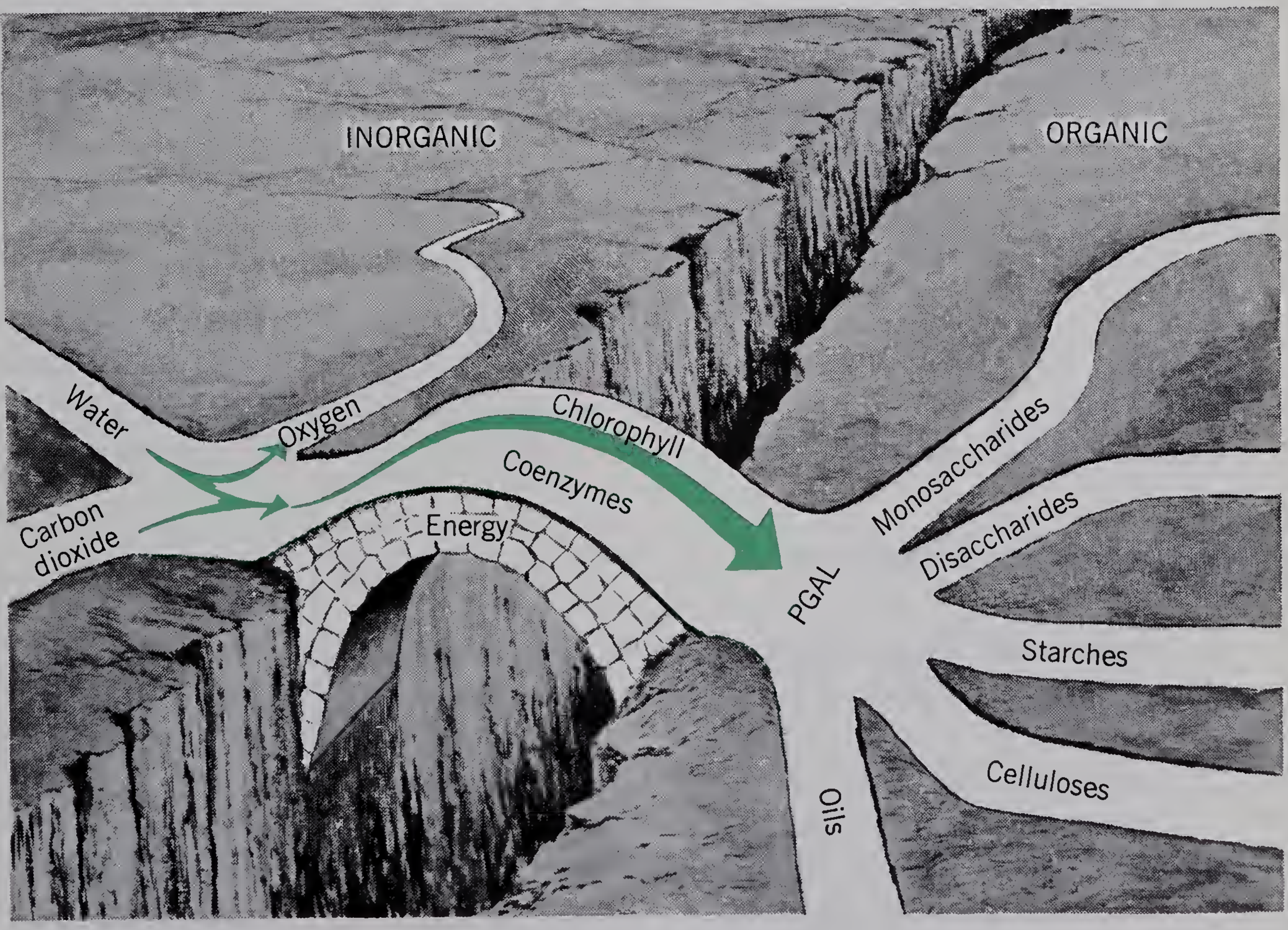


6-9 The absorption spectrum of chlorophyll in alcohol. Note that most of the green light is reflected.

provides the chemical link between the inorganic and the organic chemical worlds. You might liken photosynthesis to the crossing of a chemical bridge, with carbon dioxide and water on one side and PGAL and glucose on the other. Chlorophyll, coenzymes, and energy form the bridge.

In discussing the food relations of organisms, we refer to green plants as ***autotrophs*** (*ot*-oh-trohfs). This term means "self-feeders" and refers to the capability of these organisms to organize organic molecules. Organisms lacking this capacity are classed as ***heterotrophs*** (*het*-e-ro-trohf), or "other feeders." Animals and nongreen plants such as fungi are among these nutritionally dependent organisms. While many heterotrophs have remarkable chemical abilities, none can produce a molecule of glucose from inorganic materials. In other words, they lack the capacity for photosynthesis and must rely on autotrophs for their basic chemical requirements.

Chemosynthesis. Our discussion of carbohydrate synthesis would not be complete without a brief discussion of a small but very important group of organisms which do not rely on photosynthesis. Certain bacteria organize carbohydrates without using light energy by a process known as ***chemosynthesis.*** These bacteria have enzyme systems which are capable of trapping energy released during inorganic chemical reactions. Certain of these bacteria are able to add oxygen to hydrogen to form water. Others change ammonia to nitrites and nitrites to nitrates. Still others receive energy from reactions involv-



6-10 Photosynthesis may be likened to a chemical bridge between the inorganic and the organic world.

ing iron compounds and sulfur compounds. Energy from these reactions is used in synthesizing carbohydrates from carbon dioxide. From carbohydrate molecules, chemosynthetic bacteria can form all of their fats, proteins, and nucleic acids. We consider bacteria lowly organisms. But are these organisms lowly? From the standpoint of cell structure and specialization they are. But from the standpoint of cell chemistry, they are probably as well equipped as any organisms in existence. We, who rank among the most nutritionally dependent of all forms of life, would find life much simpler if we shared the remarkable chemical capabilities of these chemosynthetic bacteria.

IN CONCLUSION

Having studied cell nutrition we might conclude that the living world is powered by sunshine. Organic compounds are the media in which solar energy is trapped, stored, transported, and made available to living cells. Each day the sun illuminates the vegetation of the earth, and new energy enters into the processes that sustain life and build the structures of living organisms. There is a wide gap between solar energy and energy release in the mitochondria of every living cell. The green plant bridges this gap with its photosynthetic abilities — a chemical capability that places it in a key position in the living world.

Having explored the nutritional activities of living cells, we now shift our study to further cell processes. Cells synthesize protein, they respire, they excrete wastes, and they secrete special substances. These are cell activities we will explore in the next chapter.

BIOLOGICALLY SPEAKING

ADP
ATP
autotroph
carbon dioxide acceptor
chemosynthesis
chlorophyll
dark reaction
energy carrier
heterotroph
hydrogen acceptor
light reaction
photosynthesis

QUESTIONS FOR REVIEW

1. Explain why living organisms require a continuous supply of new energy.
2. Explain the relationship of chlorophyll molecules to the grana of chloroplasts.
3. List various forms of chlorophyll found in different plant cells. Which form is necessary for photosynthesis?
4. Why is *Chlorella* an ideal organism to use in research in photosynthesis?
5. What is energized chlorophyll? What part does it play in photosynthesis?
6. Explain how we know that water molecules are split during the light reaction.

7. Explain the importance of ADP and ATP in photosynthesis.
8. Explain the relationship of TPN and hydrogen in the dark reaction.
9. Outline the steps in the fixation of carbon dioxide in the dark reaction.
10. Describe the chemical reactions involved in the conversion of PGA to PGAL.
11. List several organic compounds that may be formed from PGAL.
12. Explain why chloroplasts appear green.
13. In what respect is chemosynthesis fundamentally different from photosynthesis?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the matter and energy relationships in an energy carrier such as ATP.
2. Explain how RDP is involved in a cycle in the dark reaction of photosynthesis.
3. Discuss the nutritional relationship between autotrophs and heterotrophs.

CHAPTER 7

CELL METABOLISM

Cell metabolism. All the processes of a cell that relate to the use of food are included in ***metabolism.*** Certain of these processes are building activities. As you learned in the last chapter, the building activity most significant to life is photosynthesis, in which fuel molecules in the form of carbohydrates are synthesized. Other building processes include the synthesis of proteins. This results in growth and repair of the cell structures — its cytoplasm and membrane, cytoplasmic inclusions, and nuclear structures. In all of these processes, molecules are built up. Simple molecules are used in organizing more complex molecules. We refer to these building activities, or the constructive phase of metabolism, as ***anabolism.***

Equally important is the destructive phase of metabolism, known as ***catabolism.*** In this phase large molecules are broken down and chemical energy is released, some as heat and some as energy to support all of the chemical activities of the cell. We may think of this energy output in terms of muscle activity as we move our bodies, or nerve impulses as we think and reason and receive impressions from our sense organs. However, all of this activity and every other life-supporting process requires a constant energy supply from fuel molecules split in the tiny "powerhouses" of our cells.

Protein synthesis. While photosynthesis is limited to the cells of autotrophs, this cannot be said of ***protein synthesis.*** No living matter has ever been found which does not contain protein. Every cell organizes its own protein molecules. Thus protein synthesis is a universal phase of cell anabolism.

There is another striking difference between protein synthesis and carbohydrate synthesis. All cells capable of photosynthesis organize the same PGAL and glucose molecules in the same series of chemical reactions. This is not true of proteins. A cell builds specific proteins which vary from species to species, individual to individual, and, to some extent, in various kinds of cells in the same organism. You may have read accounts of attempts to transplant tissues or organs from one individual to another. These transplants are almost always unsuccessful, except between identical twins, because the unique proteins of the recipient set up a reaction to the donor's quite different proteins.

A cell thus expresses individuality in protein synthesis. How is this synthesis regulated? What sort of cellular code determines exactly what proteins will be formed and how these molecules are to be constructed? This is a fascinating story. However, before we explore the "protein factories" of a cell, we will take a closer look at cell proteins.

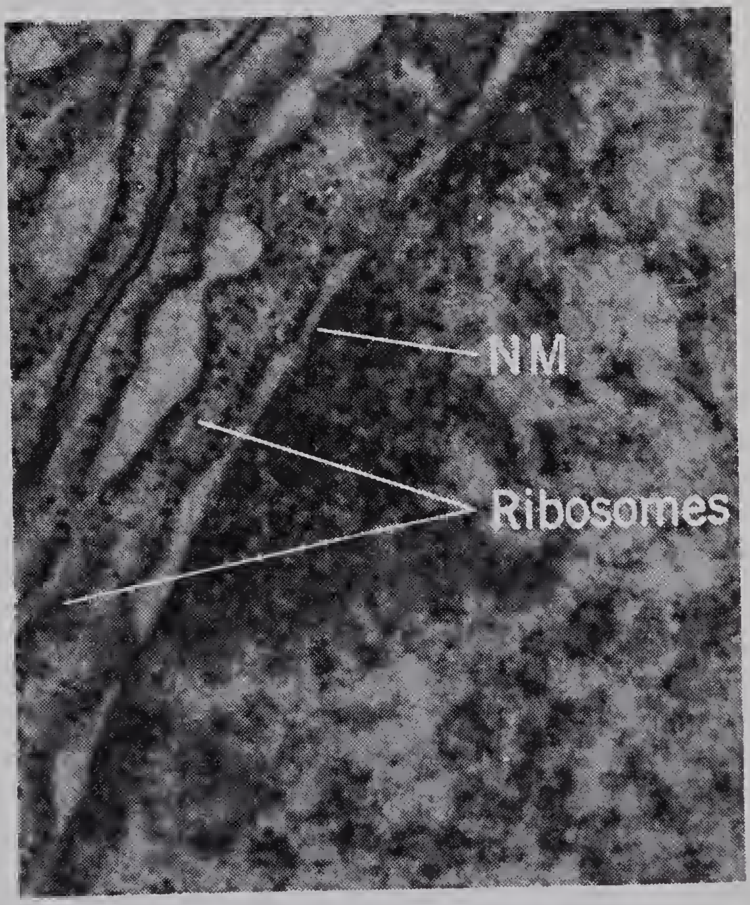
Functions and organization of proteins. Proteins serve many functions in living cells. Some are *structural proteins.* These molecules remain in the cell and form its various parts — its cytoplasm, membranes, and the various cytoplasmic inclusions. *Enzymes* are protein molecules which are essential in all of the cell's chemical activities. We classify these as *intracellular* when they remain in the cell. Other enzymes are *extracellular.* These enzymes are secreted from the cell and act as catalysts in chemical reactions in other regions of the organism. Digestive enzymes are extracellular. Still other proteins are *hormones,* which regulate specific activities often far removed from the cells that produce them. Other proteins form pigments in plant cells, the hemoglobin in red corpuscles, and the proteins composing blood serum. These are but a few of the protein substances synthesized in cells. We can summarize the importance of proteins by stating that they are *indispensable for life.*

Various proteins are composed of different numbers and arrangements of approximately 20 subunits, or amino acids. The amino acids are linked together in a linear chain. Other groups of atoms are attached to the amino acid chains to form molecules of amazing complexity. The size and complexity of protein molecules is indicated in their formulas, in which the number of atoms may range from a few thousand to several million in the extremely complex and largest of all molecules.

The way in which amino acids are arranged to form a specific protein is determined by a chemical code within the cell. We must return to the DNA molecule in order to understand the nature of this synthesis.

Cell protein factories and instructions from "headquarters." We know that the ribosomes are the centers of protein synthesis. It is in these "factories" that amino acids are joined in the organization of protein molecules. However, the exact structure of these proteins is determined by DNA molecules in the nucleus. How, then, is a pattern, or "blueprint," delivered from the nucleus to the ribosome factories?

Biologists know that a molecule of DNA bears a genetic code formed by its nitrogen-containing bases. It would be well to review the arrangement of these bases, which we described in Chapter 3, before discussing their importance in protein synthesis. Four kinds of bases are present in the nucleotides of DNA



7-1 Electron micrograph of part of a cell from the pancreas of a frog. The nuclear membrane is marked NM. The numerous ribosomes appear as dense granules in the cytoplasm. (K. R. Porter) molecules. These are adenine, thymine, guanine, and cytosine, designated by the letters A, T, G, and C. The bases are paired in the double-strand DNA molecule as A–T or T–A and G–C or C–G. RNA molecules contain all of these bases except thymine, for which uracil (*yur*-a-sil), another base, is substituted. Thus, the bases in RNA may be designated as A, U, G, and C.

The bases in a strand of DNA may occur in any linear sequence. However, biologists have found that it is not single bases but groups of three, or triplets, that function in the control of protein formation. In your study of protein synthesis you will discover how these triplet bases determine exactly what amino acids will be attached in chains to form specific proteins called for by DNA in the nucleus. This is a fascinating discovery of recent years.

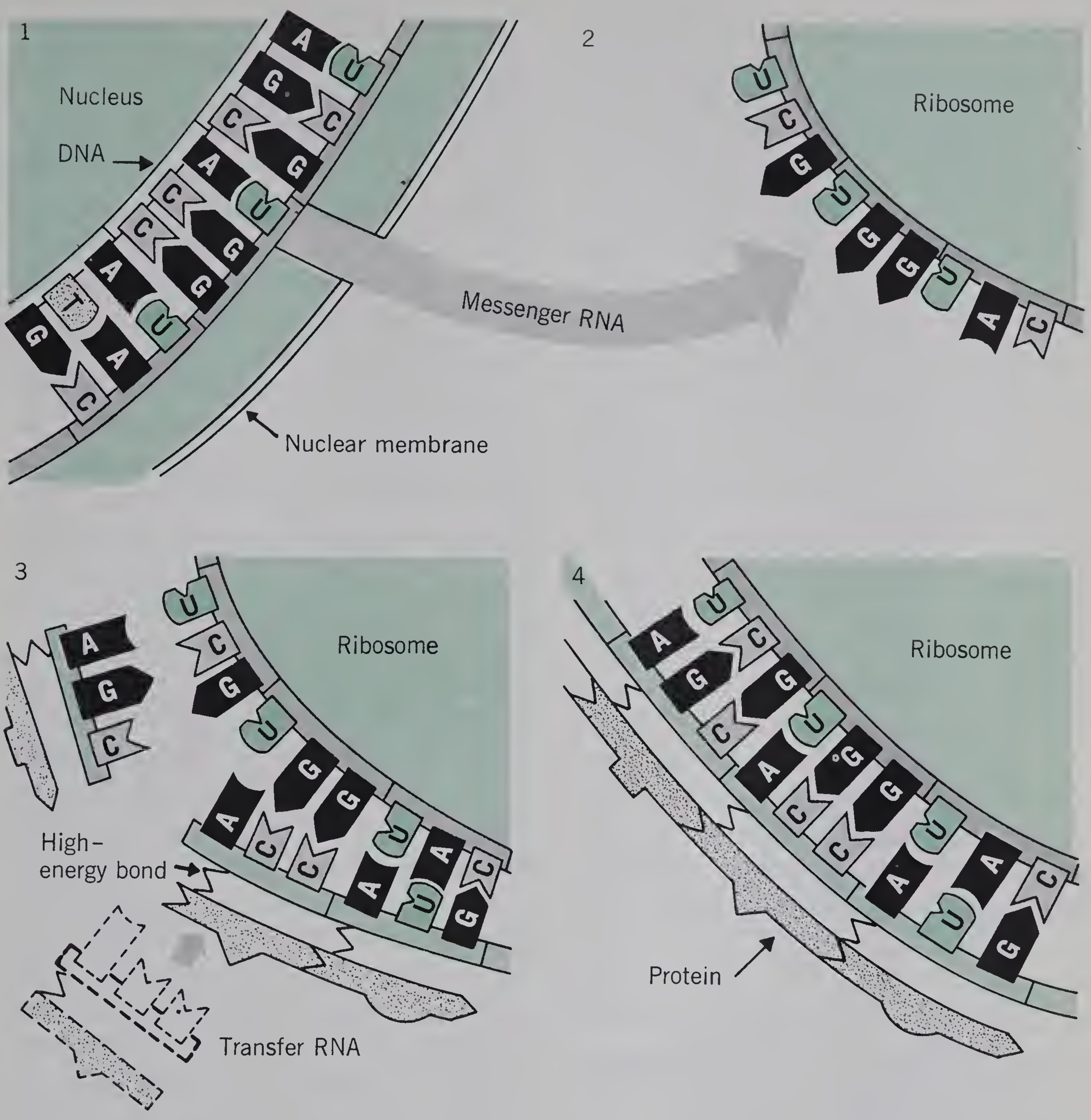
Let us assume that three sets of the base triplets in a strand of DNA are arranged as AGC, ACC, ATG. You will find these in Diagram 1 in Fig. 7–2. If this is the left helix of a double strand of DNA, its mate, the right helix (not shown), has matching but not duplicate bases TCG, TGG, TAC.

We know that DNA in the nucleus controls the synthesis of proteins on the surface of ribosomes in the cytoplasm. Yet, the DNA does not leave the nucleus in the process. Somehow, DNA must deliver its message to the ribosomes. How is this information relayed to the ribosomes? This involves a form of RNA known as ***messenger RNA.*** If you study Fig. 7–2 closely, you will see how the messenger RNA receives its code in the nucleus and determines just what protein will be formed on the surface of a ribosome.

Diagram 1 in Fig. 7–2 shows a single helix of DNA in the process of forming a strand of messenger RNA in the nucleus. Three sets of base triplets are shown in the DNA: AGC, ACC, ATG. Corresponding bases in the messenger RNA are UCG, UGG, UAC. Notice that U (uracil) is substituted for T (thymine) in the RNA. You might compare the base structure of DNA and messenger RNA to a positive print of a photograph and the negative. One is the reverse, or the complement, of the other.

As molecules of messenger RNA are formed, they may be stored in the nucleus for a time. Soon, however, they leave the nucleus and move to the ribosomes to deliver their important instructions for protein synthesis. When molecules of messenger RNA reach the ribosomes, they attach to the ribosomal surfaces and form patterns, or *templates.* These are shown in Diagram 2 in Fig. 7–2. Ribosomes contain a second kind of RNA, known as ***ribosomal RNA.*** The function of this RNA in protein synthesis is not definitely known. However, it is believed to come from the nucleus and to combine with proteins in the structure of the ribosome. There is evidence, also, that ribosomal RNA may function in the attachment of messenger RNA to the ribosome and that it may regulate the enzymes involved in activities of the ribosome.

The next question concerns delivery of amino acids to the template formed by the messenger RNA on the ribosomes. Remember that these cannot be any of the 20 amino acids that may be present in the cell, but certain ones and in a certain arrangement, as determined by DNA through its messenger RNA. This assembly of amino acids involves a third kind of RNA known as ***transfer RNA.*** Strands of transfer RNA are believed to have at one end a particular sequence of three bases in a triplet


1
Nucleus
DNA
Nuclear membrane
Messenger RNA
2
Ribosome
3
Ribosome
High-energy bond
Transfer RNA
4
Ribosome
Protein
A
G
C
U
T

7-2 Protein synthesis. 1. A single strand of DNA forms a strand of messenger RNA having complimentary bases. 2. Messenger RNA is deposited on a ribosome, where it acts as a template. 3. Transfer RNA strands bring specific amino acid molecules to the ribosome. 4. As the amino acids are laid down on the template, a protein is synthesized.

of nucleotides. These base triplets might be coded AGC, ACC, AUG, etc. Depending on the bases present in the three nucleotides, a single transfer RNA will attach *only one specific amino acid* in the cytoplasm. Furthermore, a specific enzyme seems to be involved.

Now let us return to the strand of messenger RNA which has formed a template on the ribosome. Notice in Diagram 3 in Fig. 7–2 that specific transfer RNA strands are bringing one amino acid each to the template. The first base triplets, UCG, will call for a transfer RNA coded AGC. This strand of transfer RNA will be bearing a specific amino acid known as *arginine* (*ahr*-je-neen). The second base triplet, UGG, will receive the transfer RNA containing the bases ACC, to which the amino acid *glycine* is attached. The third triplet bases, UAC, will receive transfer RNA with the base code AUG. The amino acid *histidine* (*his*-ti-deen) will be attached to this strand of transfer RNA. Now, let's line up the bases in the three strands of transfer RNA we have used. AGC, ACC, AUG — where have you seen this sequence before? With the exception of uracil in the third triplet, this was the base sequence in the nucleotides of the DNA in the nucleus. DNA duplicates its code in strands of transfer RNA by means of messenger RNA. Amino acids are joined in strands such as arginine to glycine to histidine (and many others), according to the base coding of DNA.

The assembled amino acids along the ribosome are now joined by chemical bonds. Energy for this process is believed to come from the ribosomes. The protein molecules are released and the transfer RNA is freed, as shown in Diagram 4 in Fig. 7–2. In some cells transfer RNA may attach additional amino acids and repeat the process. In others they seem to function only once.

What happens to the proteins as they are released from the ribosomes? Some may be structural proteins, but most are believed to be enzymes. These enzymes regulate all of the chemical activities of the cell.

Cellular respiration. So far we have discussed only synthetic processes of the cell in which complex molecules are formed and molecular energy is built up. We now shift our discussion to the breakdown of molecules and the release of chemical energy. All of the activities of a living cell require a continuous supply of energy. This energy must be released within the cell during the process known as ***respiration.*** It constitutes a vital part of the destructive or catabolic phase of metabolism.

You are familiar with the degrading of organic fuel molecules and the transformation of chemical energy to heat, light, and mechanical energy. This happens when you burn gasoline in your automobile engine, heat your house with fuel oil, gas, or coal, or burn a log in your fireplace. The energy released during combustion of these organic fuels is solar energy, present in molecules since they were formed originally by photosynthesis. The energy is released as the fuel molecules are degraded by oxidation. As you know, this oxidation requires a high temperature. Furthermore, the oxidation that occurs is uncontrolled in that almost all of the molecules are broken down. While there is some similarity between the oxidation of fuels during combustion and the degrading of fuel molecules in a cell, there are also many differences. The cell mitochondria, in which much of respiration occurs, could not withstand the high temperatures of fuel combustion. Furthermore, oxidation in a cell is controlled, so that it occurs in small steps, each of which releases small quantities of energy. How can organic fuel molecules be degraded at the normal temperature of an organism? Respiratory enzymes accomplish this and control the process as well.

When you think of respiration in your own body, you probably think of gaseous exchanges during breathing. While we are most aware of breathing and the intake and exhalation of gases, remember that this phase of the process is a gaseous exchange between the blood and the atmosphere. The actual seat of respiration is the body cells and, more specifically, the mitochondria of these cells. It is here that the cellular "fires" burn constantly.

The fuel for respiration. Any organic molecules present in a cell may be a fuel for respiration. These include carbohydrates in the form of glucose molecules, fatty acids and glycerol, amino acids, and even vitamins and enzymes.

In Chapter 3 we discussed the chemical bonds that hold atoms together in a molecule. These bonds are electrical forces and are referred to as chemical energy. As long as they remain, the molecule contains stored chemical energy. When the molecule is decomposed to atoms or simpler molecules, this energy is set free. Organic fuels used in respiration contain energy that was once solar energy that has been locked in molecules since they were organized from simpler molecules during photosynthesis. Thus the energy liberated in respiration is chemical bond energy which was once light energy.

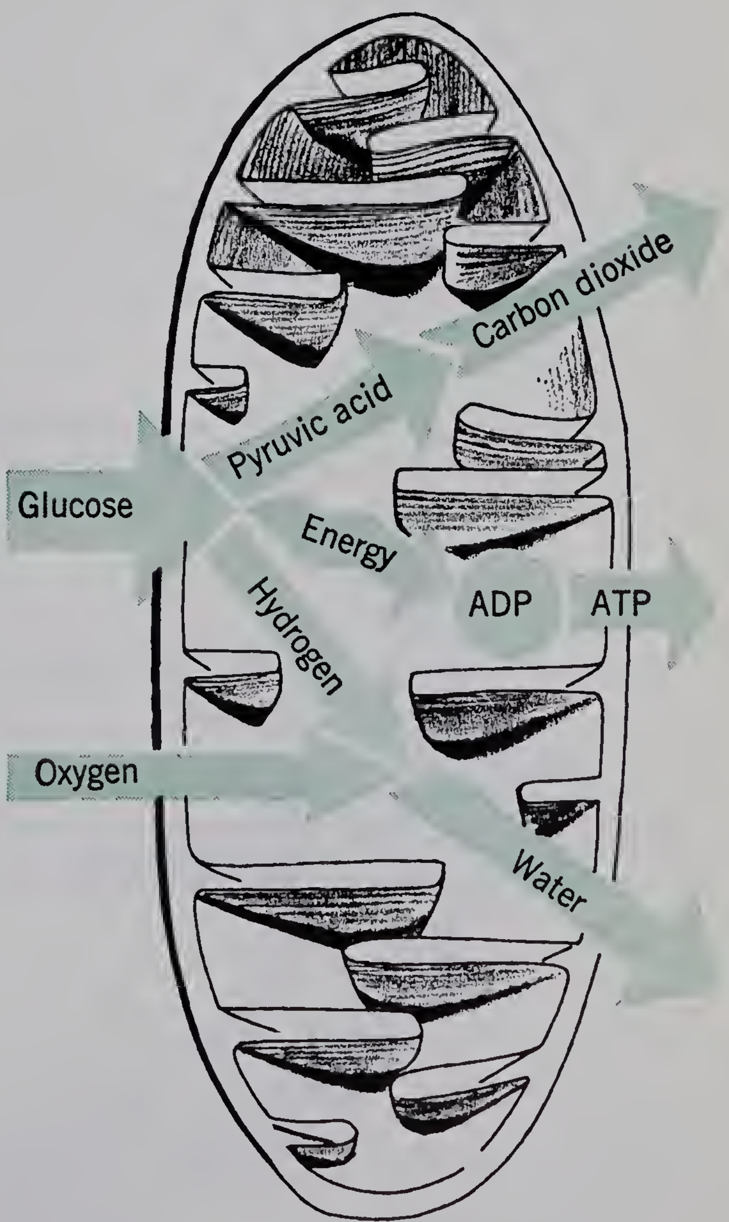
The energy released in a cell during respiration results from oxidation of glucose. ***Oxidation*** involves either the addition of oxygen or the removal of hydrogen from a molecule, with an accompanying release of energy. Most of the oxidation in a cell is brought about by the removal of hydrogen.

Three products result from the oxidation of glucose during respiration: 1. fuel fragments; 2. hydrogen; and 3. energy. Fuel fragments include the smaller molecules resulting from the breakdown of glucose. If respiration is complete, the fuel fragment is carbon dioxide. Hydrogen removed from glucose molecules combines with a hydrogen acceptor. Energy released from glucose is trapped in ATP in much the same way as it was in the case of photosynthesis.

Various forms of respiration. Chemical changes involved in various forms of respiration are extremely complex and need not be described in detail, since we are concerned primarily with energy release and end products. We will describe three forms of respiration in simple steps.

If free atmospheric oxygen is the hydrogen acceptor, we refer to the process as ***aerobic respiration*** (a-*roh*-bik). We can summarize this process in the following steps:

1. Molecules of glucose ($C_6H_{12}O_6$) are split into two molecules of a 3-carbon compound ($C_3H_6O_3$) by enzyme action.
2. Other respiratory enzymes break down these molecules to *pyruvic acid*



7-3 The chemical changes involved in aerobic respiration are summarized in this diagram of a mitochondrion.

(py-*roo*-vik) ($C_3H_4O_3$) and hydrogen (H_2).

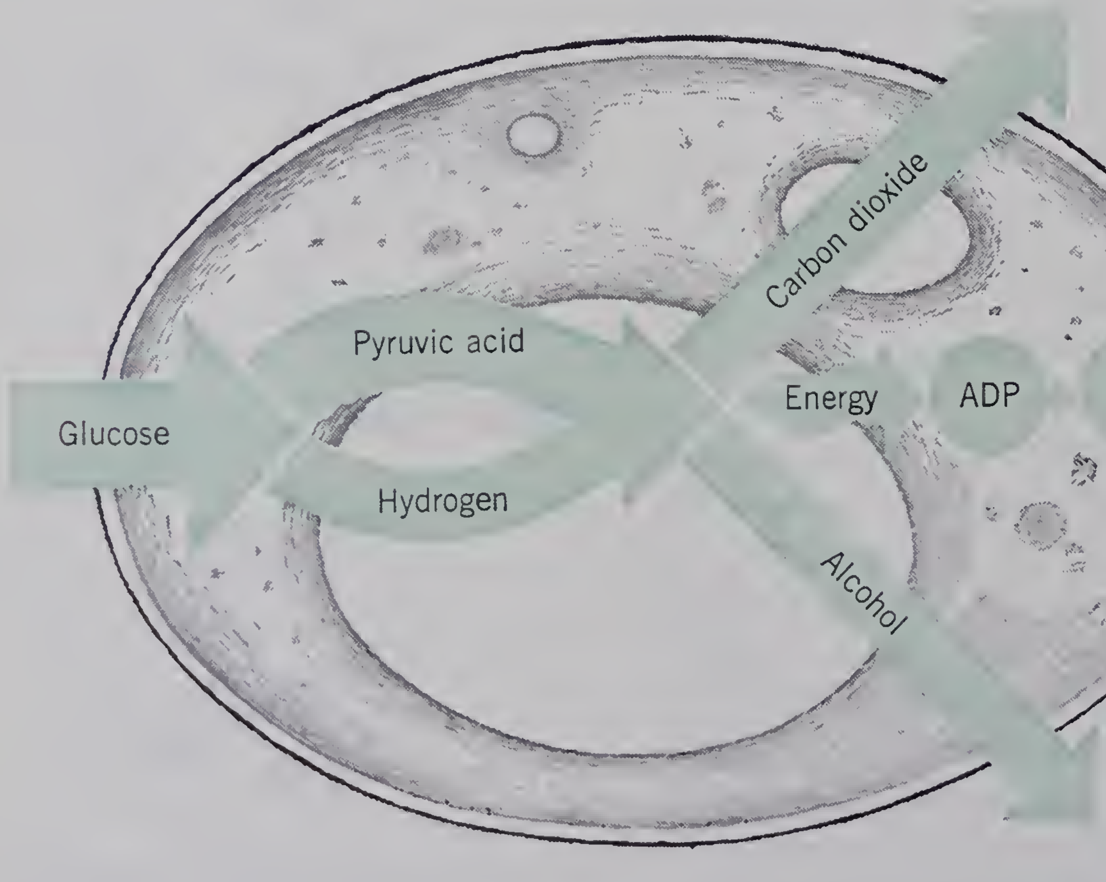
3. Atmospheric oxygen serves as the hydrogen acceptor, with the result that water is formed.
4. Energy is released.
5. Pyruvic acid is completely changed to carbon dioxide and water.

In a second kind of respiration, certain bacteria release oxygen from chemical compounds such as nitrates and use this oxygen, rather than atmospheric oxygen, as the hydrogen acceptor in the oxidation of glucose. We refer to this process as ***anaerobic respiration*** (an-a-*roh*-bik).

A third kind of glucose oxidation is known as ***fermentation,*** which is also a form of anaerobic respiration. In fermentation glucose is split into molecules of pyruvic acid. Hydrogen recombines with pyruvic acid or with some other organic molecule formed from pyruvic acid. In certain bacteria and animals *lactic acid* (*lak*-tik) is a product of fermentation. Plants, yeasts, and certain bacteria form alcohol during fermentation. In both kinds of fermentation, carbon dioxide is formed as a fuel fragment. Since both lactic acid and alcohol are high energy organic compounds, little energy is released during fermentation.

Energy transport in a cell. What happens to the energy released in the mitochondria during respiration? Some of it is given off as heat. In a warm-blooded animal this heat maintains a constant body temperature. In cold-blooded animals and plants, however, heat energy from respiration is of little value. The remaining energy must support cell activities. The question, then, is how this energy can be trapped and transported from the mitochondria to all the substances and structures of the cell.

We discussed ADP (adenosine diphosphate) and ATP (adenosine triphosphate) as energy carriers in photosynthesis. These compounds are also involved in respiration. Energy re-



7-4 The chemical changes involved in fermentation are summarized in this diagram of a yeast cell.

leased from the oxidation of glucose is used in adding a phosphate group to a molecule of ADP. This results in ATP, a higher energy compound. ATP may move to any part of the cell and supply energy as it is needed. The removal of one phosphate group from ATP releases energy and reforms ADP, which can then receive more energy. We may show these changes, both of which require enzymes, in a simple equation:

$$\text{ADP} + \text{phosphate} + \text{energy} \rightleftarrows \text{ATP}$$

Think of these compounds as a portable bank. ADP is the receiving window, while ATP is the paying window. Energy is the money. Energy released in the mitochondria is deposited in the bank at the receiving window when a phosphate group is added to ADP. The energy is now in the bank as bond energy in the high energy compound, ATP. Securely locked in these molecules, the energy is transported to all parts of the cell. As energy is needed in cell activities, ATP molecules are changed to ADP with energy release. Thus ATP is the energy vault, the energy transport system, and the energy-yielding substance of respiration.

Respiration is a continuous process in every cell. Each cell functions as a tiny power plant in liberating the energy required for its many activities. Deprived of this energy, even for an instant, the cell dies.

IN CONCLUSION

Cell metabolism involves both constructive processes that use energy and destructive processes that release it. Carbohydrate and protein synthesis are anabolic processes, while respiration is catabolic.

DNA holds the key to protein synthesis. Every cell organizes its own protein molecules according to instructions received from the DNA molecule by way of messenger RNA. There are as many kinds of proteins as there are forms of DNA.

In respiration an organic fuel is oxidized, usually by the removal of hydrogen, with a resulting release of energy. Respiration may be aerobic, anaerobic, or in the form of fermentation. The energy released in respiration is transported in the cell by ATP.

Having discussed the various ways the cell maintains itself and grows, we shall in the next chapter study the way the cell reproduces. Our knowledge of this process has been very much enhanced by discoveries made possible with the electron microscope.

BIOLOGICALLY SPEAKING

aerobic respiration
anabolism
anaerobic respiration
catabolism
fermentation
messenger RNA
metabolism
oxidation
protein synthesis
respiration
ribosomal RNA
transfer RNA

QUESTIONS FOR REVIEW

1. Define metabolism by naming and describing its constructive and destructive phases.
2. Give two differences between carbohydrate and protein synthesis.
3. List several kinds of protein materials formed in cells.
4. What is the structural difference between DNA and RNA?
5. Describe the function of messenger RNA in protein synthesis.
6. Describe the function of transfer RNA in protein synthesis.
7. What is the relationship between the base sequence in DNA and that in transfer RNA? What is the significance of this relationship?
8. Define the process by which energy is released in cell respiration.
9. What three products result from cell respiration?
10. Describe briefly the process by which energy is transported in the cell.

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the chemical mechanism by which DNA controls protein synthesis.
2. Explain why proteins are specific in living organisms.
3. There are four kinds of bases in the DNA molecule and there are about 20 amino acids. Supposing the amino acid code consisted of two bases instead of three, how many amino acids could be coded?
4. Why is an energy transport system vital to a cell?

CHAPTER 8

CELL GROWTH AND REPRODUCTION

Growth of cells. One of the results of protein synthesis in a cell is replacement of worn-out structures. The rate of synthesis, however, normally exceeds the requirements of materials for repair and replacement. Accumulation of these additional materials results in growth of the cell.

Is there a limit to the size a cell may reach? Writers of science fiction have constructed weird tales of cells that did not stop growing. Giant blobs of protoplasm move into cities and flow down streets, engulfing terrorized people who cannot escape. While stories such as these make fascinating reading, you know that they could never happen. Do you know why?

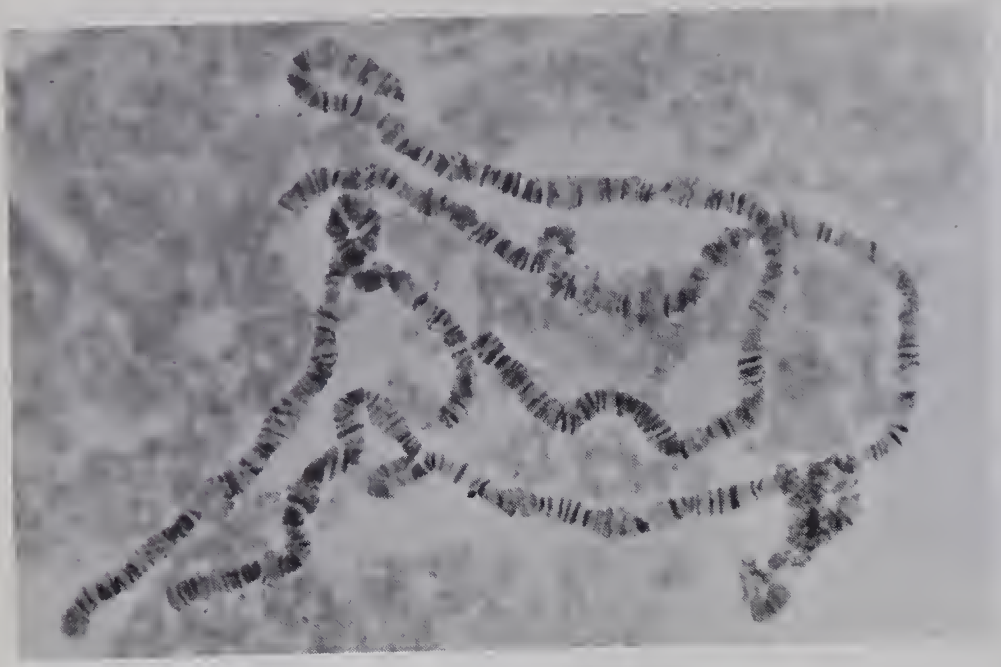
As a cell adds to its substance, one of two things must happen. Either its rate of synthesis must reduce or it must divide its mass. Otherwise its mass would lead to its own destruction.

Why cells divide. All of the materials necessary to support the life-sustaining processes of a cell must enter through its enveloping membrane. Furthermore, all of the waste products resulting from chemical reactions within the cell must pass through this membrane. Thus, there is a critical relationship between the volume of cell content and the surface exposure of the membrane. As a cell grows, its protoplasmic volume increases, but its membrane surface does not increase proportionally. Supplying the protoplasmic content becomes an increasing problem.

What is the logical solution? Division of the cell will reduce the amount of cell substance and add a new membrane surface between two masses. The cell is now two smaller cells, each rejuvenated by division of the original mass.

The nature of cell division. Cell growth, or increase in size, is normally followed by cell division, or increase in number. Since cell division involves the splitting of a cell, biologists refer to the process as *fission* (*fish*-in). Most cells divide into two approximately equal parts, or undergo ***binary fission.***

We designate a cell that has undergone growth and is ready to divide as a ***mother cell.*** The division of a mother cell results in two approximately equal ***daughter cells.*** Fission generally involves two distinct phases. One is the duplication of nuclear materials, as a result of which each daughter cell receives nuclear materials that are identical to those of the mother cell. This duplication of nuclear materials maintains the characteristics of a cell in all of its descendants. The first cell of your body contained a specific DNA compo-



8-1 This photomicrograph shows the chromosomes in the nucleus of a cell from the salivary gland of a fruit fly. (Bausch and Lomb, Inc.)

sition that was different from that of any other human being. Now your body is composed of several billion cells, all with identical DNA composition because of nuclear duplication each time a cell divides. We refer to the events in which nuclear materials are duplicated as ***mitosis*** (my-*toh*-sis).

The second phase of cell fission is division, or ***cleavage,*** of the cytoplasm into two approximately equal parts. This phase of the process involves a mechanical separation of cytoplasmic structures of the mother cell by a membrane or a wall. Obviously, mitotic division of the nucleus must precede cleavage of the cytoplasm.

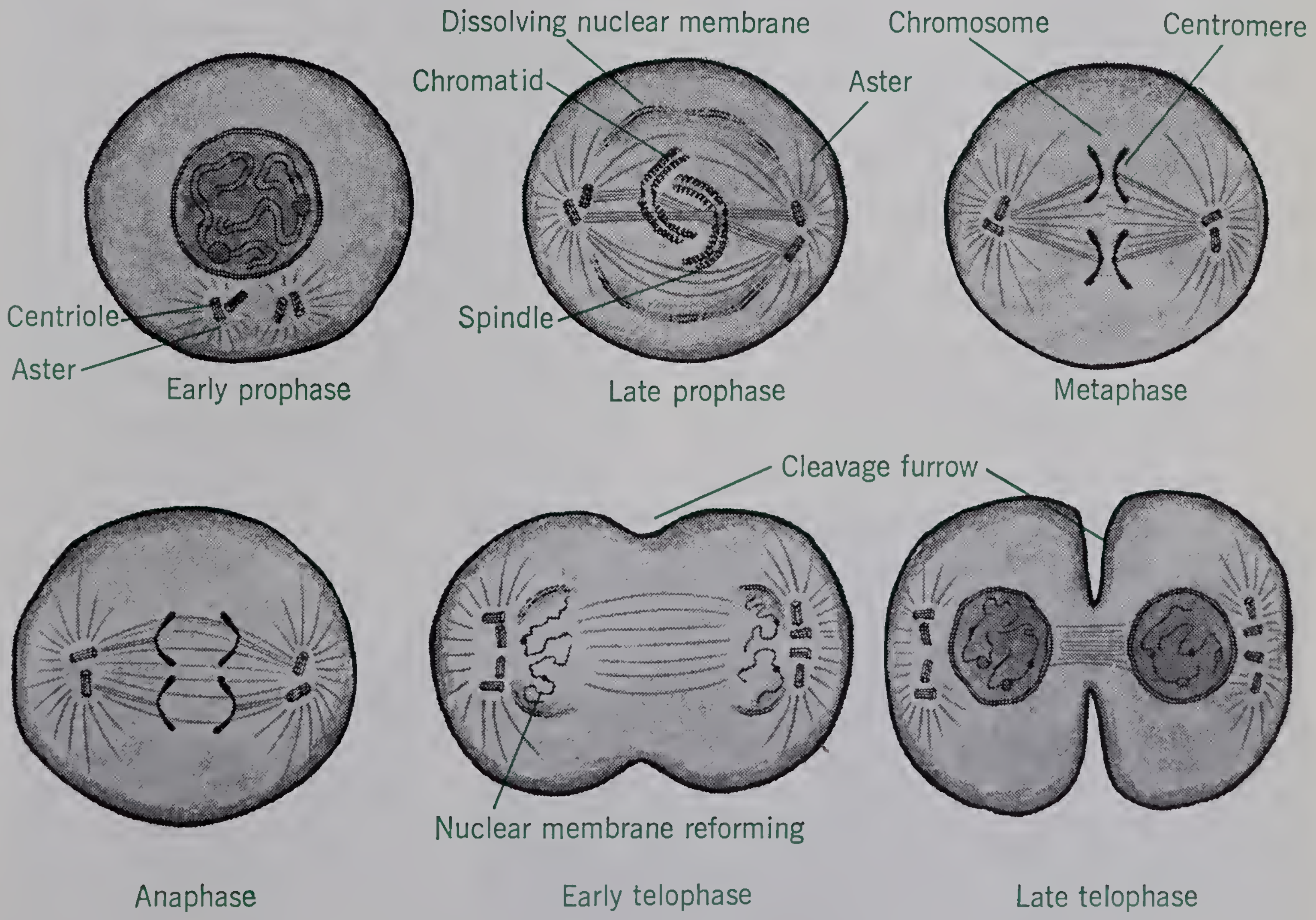
Mitotic division. Before we discuss the sequence of events occurring in mitosis, it would be well to review certain of the nuclear structures discussed in Chapter 4. The key components of the nucleus are molecules of DNA. These complex molecules bear the genetic code of the cell as determined by the nature and sequence of their bases (purines and pyrimidines) joined in the double helix of the molecule. These groups of bases in a strand of DNA which express genetic traits are known as *genes*. DNA strands are spiraled around protein molecules to form *chromosomes*.

Generally, mitosis includes the self-duplication of DNA and other chromosomal materials and the equal distribution of these materials to two daughter nuclei. We frequently divide the sequence of events during mitosis into stages or phases, as follows: 1. interphase; 2. prophase; 3. metaphase; 4. anaphase; 5. telophase. These stages are not identified by abrupt changes. However, certain significant events occur which will make it possible for you to distinguish each stage.

Interphase. Following the formation of a daughter cell and prior to a subsequent division, there is a period of growth and enlargement. Until recently biologists thought the nucleus was inactive during this period, referred to as the ***interphase.*** This was a logical conclusion since changes occurring in the nucleus at this time are not microscopically visible. Today, however, we know that the nucleus, in addition to directing the all-important protein synthesis, is preparing for a coming division during at least the latter part of the interphase. DNA molecules are doubling their structure and reproducing genes and chromosomes. It appears that the double strands of nucleotides forming the DNA molecules separate, as you might split a ladder by cutting through the middle of its rungs. Each side piece and attached purines and pyrimidines reconstructs its missing portions. The result is identical molecules joined lengthwise. We refer to this self-duplication of DNA as ***replication.*** Replication of DNA results in doubling of the genes and chromosomes. Thus, by the close of interphase, the nucleus contains twin DNA, genes, and chromosomes. All of this has occurred without microscopic evidence of change.

Prophase. Early stages of the ***prophase*** mark the first visible signs that a mitotic division is beginning. In animal cells perhaps the earliest event is the division of the ***centriole***, a cytoplasmic body lying just outside the nucleus. The two granular bodies resulting from this division move apart as though each repelled the other. They finally occupy positions on opposite sides of the nucleus. The cytoplasm around each centriole changes in form from sol to gel and forms fibrils which radiate from the centriole like rays from a star. These cytoplasmic fibrils are appropriately named ***asters.*** Additional fibrils form between the centrioles, bowing in the center to form a delicate structure of threads known as the ***spindle.*** In plant cells neither centrioles nor asters form. Instead a spindle of protein fibers extends from one end of the cell to the other.

During prophase the chromosomes, which were invisible in interphase, shorten and thicken and become clearly visible with the light microscope. Close examination will reveal that they are distinctly double. We now term each part of a double chromosome a ***chromatid.***


Dissolving nuclear membrane
Chromatid
Chromosome
Centromere
Aster
Centriole
Aster
Spindle
Early prophase
Late prophase
Metaphase
Cleavage furrow
Nuclear membrane reforming
Anaphase
Early telophase
Late telophase

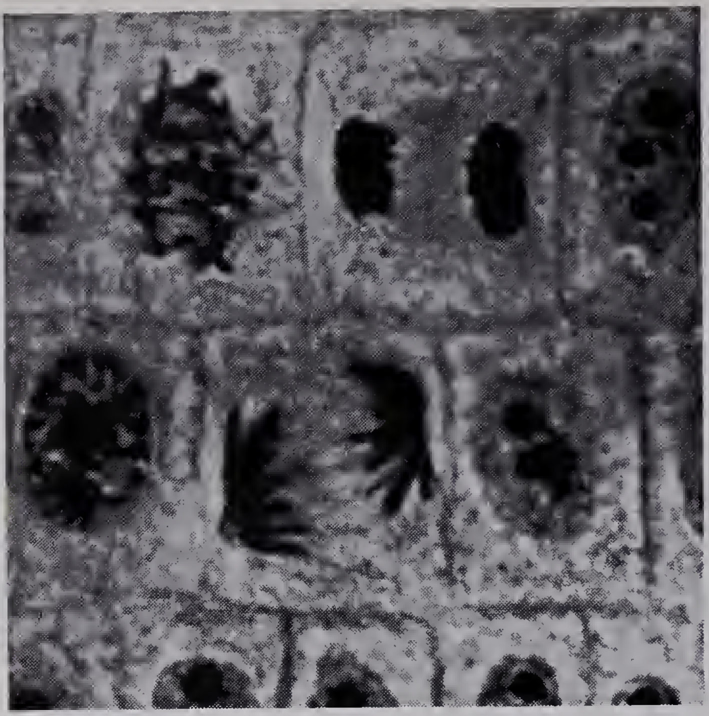
8-2 The five phases of mitosis as they occur in animal cells. In what ways does mitosis in plant cells differ from this?

A pair of chromatids is attached along its length by a single granule, known as a *centromere.*

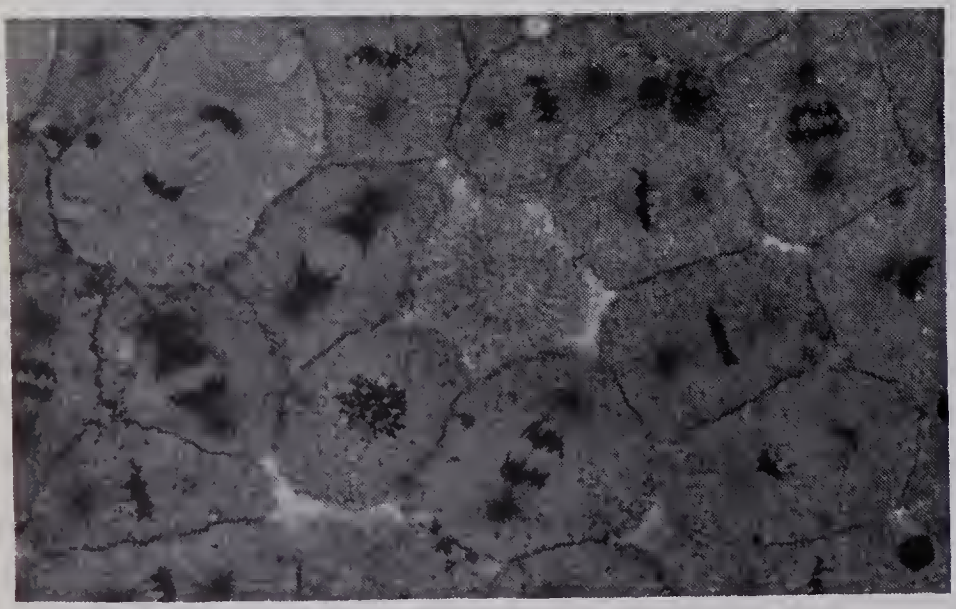
Other changes accompany chromosome shortening during mitosis. The nuclear membrane dissolves, allowing the nuclear substances to mix freely with the cytoplasm. The nucleoli disintegrate and disappear into the cytoplasm. By the end of prophase, only the joined chromatids and spindle fibers and, in animal cells, the centrioles and asters, are visible in the region of the nucleus.

Metaphase. In describing the cell spindle we often refer to each end as a pole and the point midway between the poles as the equator. You might think of the ***equatorial plate*** as a plane extending across the spindle fibers at right angles to the axis of the spindle. During ***metaphase*** each centromere moves toward the equatorial plate with its paired chromatids trailing behind it. Each centromere attaches to a thread of the spindle. Late in metaphase each centromere divides and the chromatids are separated on the spindle fiber. We now refer to them as chromosomes.

Anaphase. Immediately after division of the centromere, the freed chromosome pairs seem to repel each other. Each moves toward the pole opposite the other. Chromosome migration from equator to poles constitutes the ***anaphase*** stage of mitosis. Each chromosome moves along a spindle fiber and is apparently pulled toward the pole. Just how and why this movement occurs has not been explained. It is possible that the pull results from shortening of the spindle fiber by the removal of protein molecules. During movement toward the poles, the centromeres again lead with the chromosomes trailing behind. The anaphase ends with the arrival of the chromosomes at the poles and the formation of clusters.



8-3 Mitosis in an onion root. (Walter Dawn)



8-4 Locate as many different stages as you can of mitosis as it occurs in an animal cell. This is a photomicrograph of stained cells from a whitefish embryo. (General Biological Supply House, Inc.)

Telophase. The final stage of mitosis is marked by the reorganization of daughter nuclei and the division of the cytoplasm to form two daughter cells. Soon after reaching their respective poles, the chromosomes lengthen and gradually disappear, leaving only a granular substance in the nucleus. The spindle fibers and asters of animal cells disappear as their substance reverts from gel to sol. New nucleoli are organized and a new membrane forms around each nucleus. Reorganization of the daughter nuclei is accompanied by division of the cell into two cells of approximately equal size. This part of telophase differs distinctly in plant and animal cells.

In plant cells cellulose molecules form a wall across the cell in the region of the equator. This primary wall, or ***division plate,*** forms a common boundary between the daughter cells. In animal cells division usually begins with the appearance of an indentation, or ***cleavage furrow,*** in the region of the equator. The cleavage furrow deepens and finally constricts the cell into two parts. We mark the end of ***telophase*** and the close of mitosis with the division of the cell and the reorganization of daughter nuclei. Both cells then enter a new interphase stage.

As a result of cytoplasmic cleavage, the original mother cell has divided its cytoplasmic structures, such as ribosomes, endoplasmic reticulum, and RNA molecules. Before another division begins, these and other essential cell structures will be increased in number, as directed by DNA in the nucleus.

Significance of mitosis. As a result of mitosis, the daughter cells contain the same gene and chromosome structure as the mother cell that produced them. Furthermore, the entire cytoplasmic content of the mother cell is divided nearly equally in the process. Thus the daughter cells are both structurally and functionally like the mother cell.

In a multicellular organism cell division accomplishes cell replacement in regions where tissues are damaged. It also results in increase in the number of cells and growth of the organism.

The rate of cell division varies in different plant and animal tissues. Generally, it is most rapid in the least specialized tissues. For example, nerve tissue divides very slowly, if at all. Embryonic tissue, on the other hand, is in a continuous state of cell division. For this reason, these tissues are frequently used for the preparation of microscope slides showing cells in various stages of mitosis.

Cell division is stimulated by injury to a tissue. For example, cells in your skin undergo division slowly under normal conditions. A wound stimulates very rapid cell division and regeneration of the damaged tissues.

Cell division is also stimulated by separation of cells. Do you remember the chicken heart muscle we described in Chapter 2? This tissue lived more than 30 years and remained active as long as its mass was divided at regular intervals. The same principle applies to tissue cultures. When animal tissue, such as that composing a kidney, is ground or placed in a nutrient solution, the cells undergo rapid division. This would not have occurred in the intact kidney. It would seem that the rate of division is held in check by the presence of other cells in a tissue.

Asexual reproduction. In one-celled organisms cell division constitutes reproduction of the entire organism. This accounts for the rapid increase in the number of protozoans, algae, and bacteria in environments offering ideal con-

8-5 Vegetative reproduction in the potato. (USDA)

ditions for growth. Protozoans may divide as often as twice a day. But this rate is far exceeded by bacteria, which may divide as often as every 20 or 30 minutes!

Budding is also a form of ***asexual reproduction.*** In this process, nuclear division follows the appearance of a knob on the side of a cell. This projection, containing its own nuclear material, enlarges and becomes an independent cell, finally separating from the mother cell that produced it. Although we often associate budding with yeast cells, the process occurs in many other organisms, including molds. Even some of the lower animals such as the sponges reproduce by budding. A multicellular sponge develops from a bulge on the side of a parent organism. After a period of growth and enlargement, the sponge bud separates from the parent and becomes independent.

Vegetative reproduction is another method of asexual reproduction in higher plants. Did you ever plant potatoes? You merely cut a tuber into pieces, being careful to include one or two "eyes" in each piece. When these pieces are planted in soil, each eye will produce an entire plant. The same process occurs when you start a rose bush from a stem cutting rooted in sand or grow a pussy-willow tree by putting a cut stem in a jar of water.

Spore production is one of the most widespread methods of asexual reproduction. Spores are reproductive cells formed by divisions of special spore mother cells. Spores differ from cells composing the body of an organism in that they are discharged from the parent organism. The spores of some organisms are carried by the wind. If they are produced by aquatic organisms, they usually have whiplike structures with which they swim from the parent to a new location. Spores are usually protected by a resistant wall and may endure severe environmental conditions such as drying or freezing. Under suitable conditions a spore may germinate and form an active cell directly. That is, a spore does not fuse with another spore in the production of a new organism. While we usually associate spores with plants and plantlike organisms, you will discover in your study of microbiology certain animal-like cells that produce spores.

All forms of asexual reproduction involve the direct production of a new organism, either from a single cell or

8-6 Spore production in bread mold. (Hugh Spencer)

from a group of cells. Thus it is a highly efficient process. Organisms capable of asexual reproduction usually have the capability of increasing their numbers rapidly if conditions for growth are favorable.

Sexual reproduction. ***Sexual reproduction*** involves the fusion of two special cells. We refer to these sex cells as ***gametes*** (gah-*meets*). The fusion of gametes is termed ***fertilization,*** or *syngamy* (*sinj*-ga-me). We refer to the fusion body formed by the union of two gametes as a ***zygote*** (*zy*-goht).

In some organisms all gametes formed are alike. These are called ***isogametes.*** We cannot designate them as male or female gametes because of their structural similarity. We know that there are functional differences, however, because only certain isogametes attract each other and fuse during fertilization. ***Heterogametes,*** however, have structural differences that permit us to designate them as male or female sex cells. We refer to a male gamete as a ***sperm*** and a female gamete as an ***egg,*** or *ovum.*

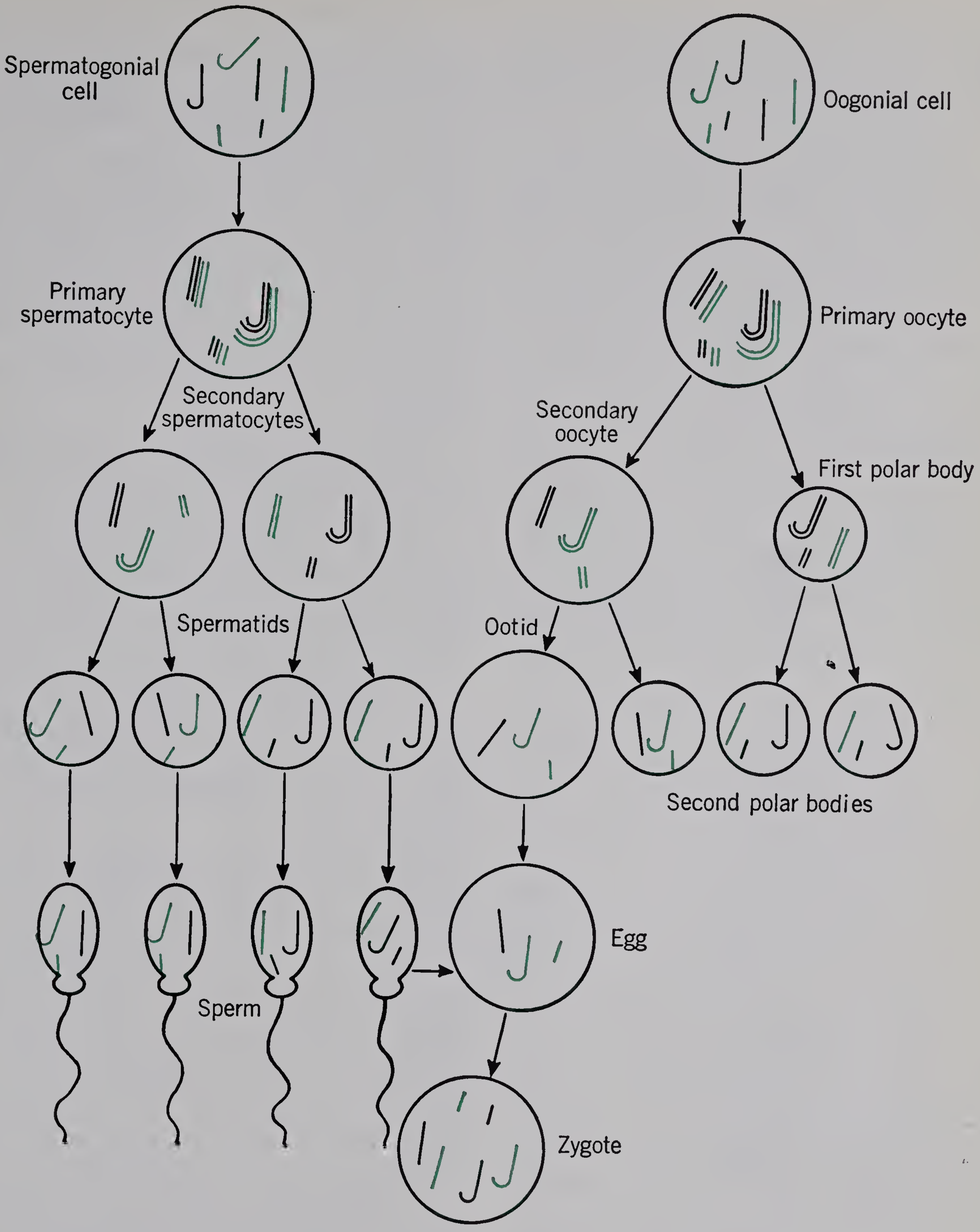
In your study of sexual reproduction in various organisms, you will find interesting differences in gamete production. You will find isogametes being produced by different individuals of a species, indicating maleness and femaleness even though the gametes are identical in form. You will also find both male and female heterogametes being produced by a single individual. More frequently, however, heterogametes are formed by different individuals which we designate as male and female parents.

Cell reproduction and chromosome numbers. Each time a cell nucleus undergoes a mitotic division, pairs of chromosomes, each composed of joined chromatids, appear during prophase and move to the equatorial plate during metaphase. We refer to the chromosomes of these pairs as ***homologous*** (hoh-*mahl*-a-gus) because they are identical in form, gene composition, and linear arrangement of genes. A ***homologue*** is a single chromosome of a homologous pair. Is the number of homologous chromosome pairs constant in all cells of an individual organism? Not only is it constant for all cells of the organism, but it is *constant for all normal individuals of a particular species.* All human body cells contain 23 pairs of chromosomes, or 46 in all. This number is constant in all human beings the world over. Furthermore, the distribution and arrangement of genes on these chromosomes is always the same. When a cell contains a full set of homologous pairs of chromosomes, we say that it has the ***diploid***, or 2*n*, chromosome number. Mitotic division maintains this chromosome number in all cells, since genes replicate and chromosomes split and form chromatids which are equally distributed in the process. Your life began as a single diploid cell containing homologous gene and chromosome pairs. Perhaps you have already figured out that one full set of genes and chromosomes came from one parent and one set from the other.

Chromosome number in gametes. If all human body cells contain 23 pairs of chromosomes, or 46 in all, would this same number be found in an egg or a sperm? If this were true, a fertilized egg would contain 92 chromosomes and all cells resulting from it by mitotic division would contain this abnormal chromosome number. This, of course, could not occur. At some time in the formation of eggs and sperm, the diploid chromosome number must be reduced to half. Wouldn't the logical biological answer be separation of the chromosome pairs? This does occur in egg and sperm formation. Each gamete contains but one chromosome of a homologous pair. We refer to this chromosome content as the ***haploid***, or *n*, number. It is important that you understand that the haploid is not merely half of the diploid chromosome number. All human eggs and sperm contain only 23 chromosomes, but not just any 23. These gametes contain one full set of homologues — one of every pair of chromosomes. You might think of an egg, then, as "half a person" even though it contains one of every kind of gene necessary to produce the new individual.

This raises an interesting biological question. If an unfertilized egg were to develop without fertilization by a sperm, would not a haploid organism develop? Did you know that this actually occurs in certain organisms? We refer to it as ***parthenogenesis.*** One of the best examples is the male, or drone, bee. Drones are produced from unfertilized eggs laid by the queen at certain times of the year. In nearly all organisms, however, an egg does not develop until fertilization has occurred. In this process each gamete contributes one full set of chromosomes. This results in a zygote with the diploid chromosome number.

Cells of the *ovaries*, which produce eggs, and those of the *testes*, from which sperm are formed, have the diploid chromosome number, like all other body cells. The question, then, is how the chromosome content is reduced to the haploid number in the formation of gametes. The science of genetics depends on this.


Spermatogonial cell
Oogonial cell
Primary spermatocyte
Primary oocyte
Secondary spermatocytes
Secondary oocyte
First polar body
Spermatids
Ootid
Second polar bodies
Egg
Sperm
Zygote

8-7 The various chromosome changes that occur during reduction division, or meiosis, resulting in the formation of eggs and sperm. The last phase represents fertilization.

Meiosis, or reduction division. The series of cell divisions involved in the formation of eggs and sperm is called ***meiosis*** (my-*oh*-sis), or ***reduction division.*** The process is shown in Fig. 8–7. In order to simplify the diagrams, we have shown only three pairs of homologous chromosomes. As we describe the formation of an egg, study the right side of the diagram closely and note the chromosome changes which occur.

The first sign of production of an egg is enlargement of an *oogonial cell* (*oh*-uh-*goh*-ne-al) in the tissue of the ovary. This cell, like all body cells, contains the diploid chromosome number. This cell will mature into the *primary oocyte* (*oh*-uh-syt).

Early in the prophase, as in mitosis, chromosomes appear and migrate to the equatorial plate. You will recall that this chromosome movement occurred in mitosis and that the chromosomes arranged at random along the equatorial plate. In meiosis, however, the homologues of each chromosome pair join throughout their lengths at the equatorial plate. We refer to this pairing of homologous chromosomes as ***synapsis.***

While the chromosome pairs are in synapsis, they shorten and thicken and coil about each other. Meanwhile, replication is occurring and chromatids appear, each "twin" joined by a centromere. This results in a *tetrad,* or group of four chromatids. We may now consider the chromosome number to be ***tetraploid*** ($4n$), since each chromatid contains a full set of genes. The coiling of chromosomes and chromatids about each other at this stage in meiosis is very important in genetics, as you will discover later. The enlarged primary oocyte, meanwhile, has formed a spindle to which the centromeres of the tetrad have attached. Paired chromatids now separate from the tetrad and move toward opposite poles. This is the anaphase stage. Note, however, that paired chromatids move together, whereas in the anaphase of mitosis they separated.

Following migration of the paired chromatids, the primary oocyte divides, forming a *secondary oocyte* and the *first polar body.* Notice that these cells contain but one of the original pair of homologous chromosomes, each now composed of joined chromatids. This is the real reduction division.

The secondary oocyte soon divides again, forming an *ootid* (*oh*-uh-tid) and a *second polar body.* In this division the chromatids separate. Both the ootid and the second polar body now contain the haploid (n) chromosome number. Meanwhile, a similar division is occurring in the first polar body. Here the joined chromatids separate and two additional second polar bodies, each with haploid (n) chromosome number, are formed.

The ootid matures into an egg. The three polar bodies have no function in reproduction and gradually disappear.

If you compare sperm production with egg formation, you will notice that the processes are similar. In the case of sperm production, however, the *primary spermatocyte* divides and forms two functioning *secondary spermatocytes.* These in turn form four *spermatids,* each of which matures into a functioning *sperm.*

Fertilization, and the restoration of the diploid chromosome number. Notice the chromosome content of the egg and the sperm in Fig. 8–7. All contain the haploid (n) chromosome number, having one homologue of each chromosome pair. Any of the sperm may fertilize the egg and produce the zygote. When this occurs, both cells contribute a homologue of a chromosome pair and the diploid ($2n$) number is re-established. Just how chromosomes are paired in this chance union depends on the specific chromosomal make-up of the egg and sperm involved in fertilization. It is the chance distribution of chromosomes during meiosis and the chance combination of chromosomes in fertilization that provides the basis for genetic variations in offspring. We will discuss many of these possibilities in the study of genetics in Unit 2.

IN CONCLUSION

The synthesis of protoplasmic substances is a never-ending process in living organisms. It began when life originated and has continued from that time to this. Each new generation receives substances from the previous generation.

Synthesis and cell reproduction are inseparable. As cells divide larger masses become smaller masses, each capable of further growth. As organisms grow and reach maturity, cells or groups of cells separate from the parents and establish new organisms. Certain reproductive processes preserve life without genetic change. This applies to mitotic division of a mother cell to form identical daughter cells, to a spore, which duplicates its parent in a new organism, and to a bud in which body cells increase a population. But organisms, in addition to increasing their cell numbers and perpetuating themselves in identical offspring, are subject to change and, by chance, to improvement. This involves new combinations of genes, made possible by sexual reproduction.

How does gametic union provide this possibility of change? Can we predict the characteristics of offspring by examining parental traits? Can a trait which neither parent possessed appear in an offspring? Questions like these will be answered in our study of genetics in the unit to follow.

BIOLOGICALLY SPEAKING

anaphase
asexual reproduction
aster
binary fission
budding
centriole
centromere
chromatid
cleavage
cleavage furrow
daughter cell
diploid
division plate
equatorial plate
fertilization
gamete
haploid
heterogamete
homologous
homologue
interphase
isogamete
meiosis
metaphase
mitosis
mother cell
parthenogenesis
prophase
reduction division
replication
sexual reproduction
sperm
spindle
spore
synapsis
telophase
tetraploid
vegetative reproduction
zygote

QUESTIONS FOR REVIEW

1. What is binary fission?
2. What two phases constitute mitotic cell division?
3. Explain the relationship between genes and chromosomes.
4. Describe the events that occur during interphase.
5. Locate the centrioles of a dividing animal cell.
6. What are asters?
7. Of what importance is the spindle during mitosis?
8. Distinguish between a chromosome and a chromatid.
9. Summarize the events that occur during prophase.
10. Explain how joined chromatids are attached to the spindle fibers.

11. Summarize the events occurring during anaphase.
12. Explain the changes that occur in chromosomes during telophase.
13. How does division of the cytoplasm differ in plant and animal cells?
14. Describe several forms of asexual reproduction.
15. Distinguish between a gamete and a spore.
16. How are isogametes different from heterogametes?
17. In what ways are homologous chromosomes alike?
18. Distinguish between the diploid and haploid chromosome number.
19. What is the basic difference between mitosis and meiosis?
20. Explain how the tetraploid number occurs briefly during meiosis.
21. Explain why a single oogonial cell gives rise, indirectly, to a single egg, while four sperm develop from a single spermatogonial cell.
22. When is the diploid chromosome number established in a zygote?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the necessity of cell division in perpetuating the life of a cell.
2. Discuss the relationship of cell division to growth and to reproduction?
3. Discuss the significance of mitosis as a reproductive process.
4. How are characteristics of an organism preserved in asexual reproductive processes?
5. Is sexual reproduction a basis for variation or change in organisms?

RELATED READING

Books

Asimov, Isaac. *The Genetic Code.* Orion Press, New York. 1963

Asimov, Isaac. *A Short History of Biology.* Doubleday and Co., Garden City, New York. 1964

Butler, J. A. V. *Inside the Living Cell: Some Secrets of Life.* Basic Books, Inc., New York. 1959

Cohn, Norman S. *Elements of Cytology.* Harcourt, Brace, and World, Cleveland. 1964

Fox, Russell. *The Science of Science.* Walker and Co., New York. 1964

Hoffman, Katherine B. and Lacey, Archie L. *Chemistry of Life.* Scholastic Book Service, Dayton, Ohio. 1964

Hutchins, Carleen M. *Life's Key—DNA: A Biological Adventure into the Unknown.* Coward-McCann, Inc., New York. 1961

Morowitz, Harold J. *Life and the Physical Sciences.* Holt, Rinehart and Winston, New York. 1963

Rowland, John. *The Polio Man: The Story of Jonas Salk.* Roy Publishers, New York. 1960

Swanson, Carl P. *The Cell.* Prentice-Hall, Inc., Englewood Cliffs, N. J. 1964

Articles

Brown, Harrison. "The Age of the Solar System." *Scientific American.* April, 1957

Pfeiffer, John E. "Enzymes." *Scientific American.* December, 1948

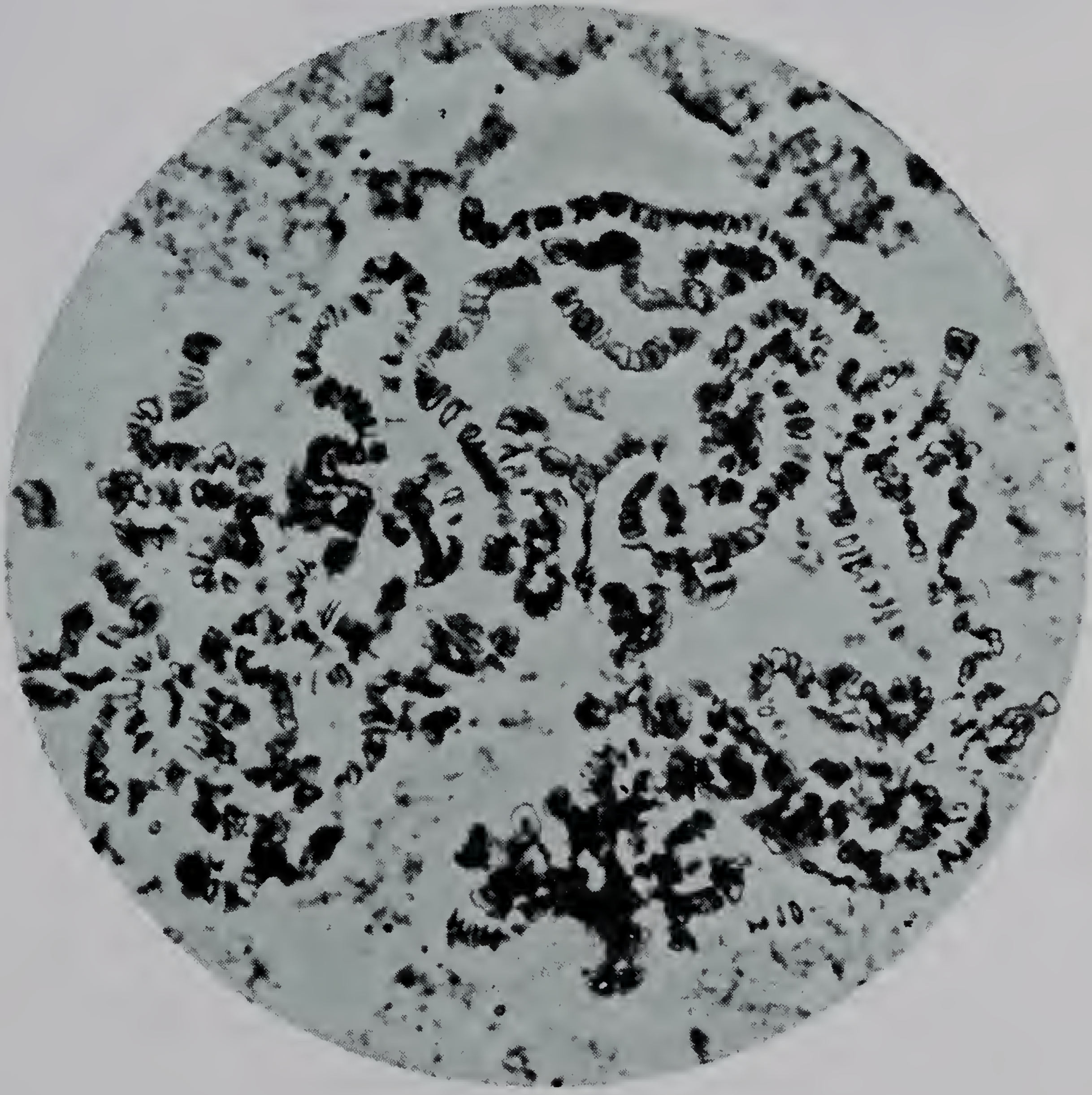
Scientific American Magazine. *Cells.* Vol. 205, September, 1961

Wald, George. "Innovation in Biology." *Scientific American.* September, 1958

Wald, George. "The Origin of Life." *Scientific American.* Aug. 1954

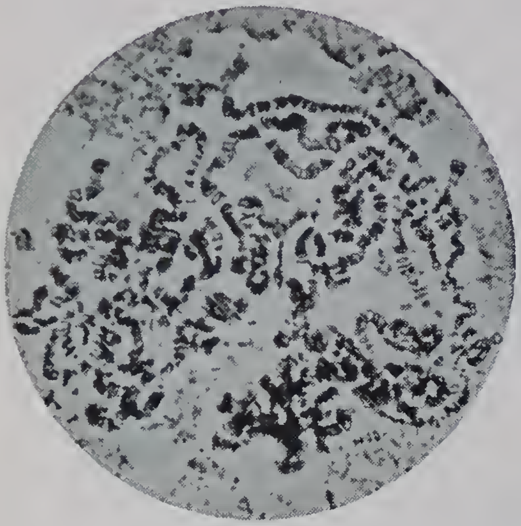
UNIT TWO

THE CONTINUITY OF LIFE



When sexual reproduction occurs in an organism, both parents transmit chemical instructions which control the development of the offspring. Each new organism resembles its parents, yet differs in some respects and so provides the basis for the mechanism of variation. What chemical controls exert this genetic influence? The answer lies in a search of cells, their nuclei and their chromosomes and finally, the nucleoproteins which compose them. Here we find the substance DNA and a genetic code expressed as genes which control the development of every inherited trait in an organism.

CHAPTER 9



PRINCIPLES OF HEREDITY

Heredity and environment. Since the day you were born, two kinds of influences have been interacting to determine your individual makeup. The first of these is heredity. ***Heredity*** is the transmission of characteristics from parents to offspring. These characteristics include the color of your hair and eyes, body build, facial features, and many others. The development of these traits is controlled by a chemical code transmitted to you through the reproductive cells of your parents. This code is contained in the genes of which chromosomes are composed. The branch of biology that is concerned with the mechanisms and substance of heredity is therefore appropriately called ***genetics.***

The second factor involved in your development is ***environment.*** This includes all the external forces that influence the expression of your heredity. It is difficult to determine where hereditary influences end and environmental ones begin. For example, body size is controlled by heredity. But it is also determined partially by diet and by the type of activity in which you participate. Similarly, the tanning of your skin is the result of the interaction of sunlight and an inherited ability to produce additional pigment. If you lack this pigment, you will sunburn rather than tan, but you will do neither if you are not exposed to the sun. Your heredity thus determines what you may become, but what kind of individual you do become depends on the interaction of your heredity and environment.

What kinds of characteristics are inherited? In certain respects all members of a species are alike. For example, man normally inherits the characteristics of the human race that make him like other human beings. These ***species characteristics*** include the ability to walk erect, hands with fingers for grasping, and a highly developed nervous system with a brain superior to that of all other organisms.

In addition to species characteristics you have inherited certain ***individual characteristics*** that make you different from all other people. Many of these characteristics are passed on from parent to offspring. The result is that you may resemble your parents to a certain degree, but be quite different from each because you have inherited characteristics from both.

Mendel's work with garden peas. In 1866, Gregor Mendel, an Austrian monk, published the results of a masterful piece of work on the laws of heredity. He was not the first to experiment in the field of inheritance, but his findings were the first of any scientific consequence. His paper, representing years of work with garden peas, was published by the Natural History Society of Brünn,

9-1 Gregor Mendel in his garden experimenting with garden peas. (Bettmann Archive)

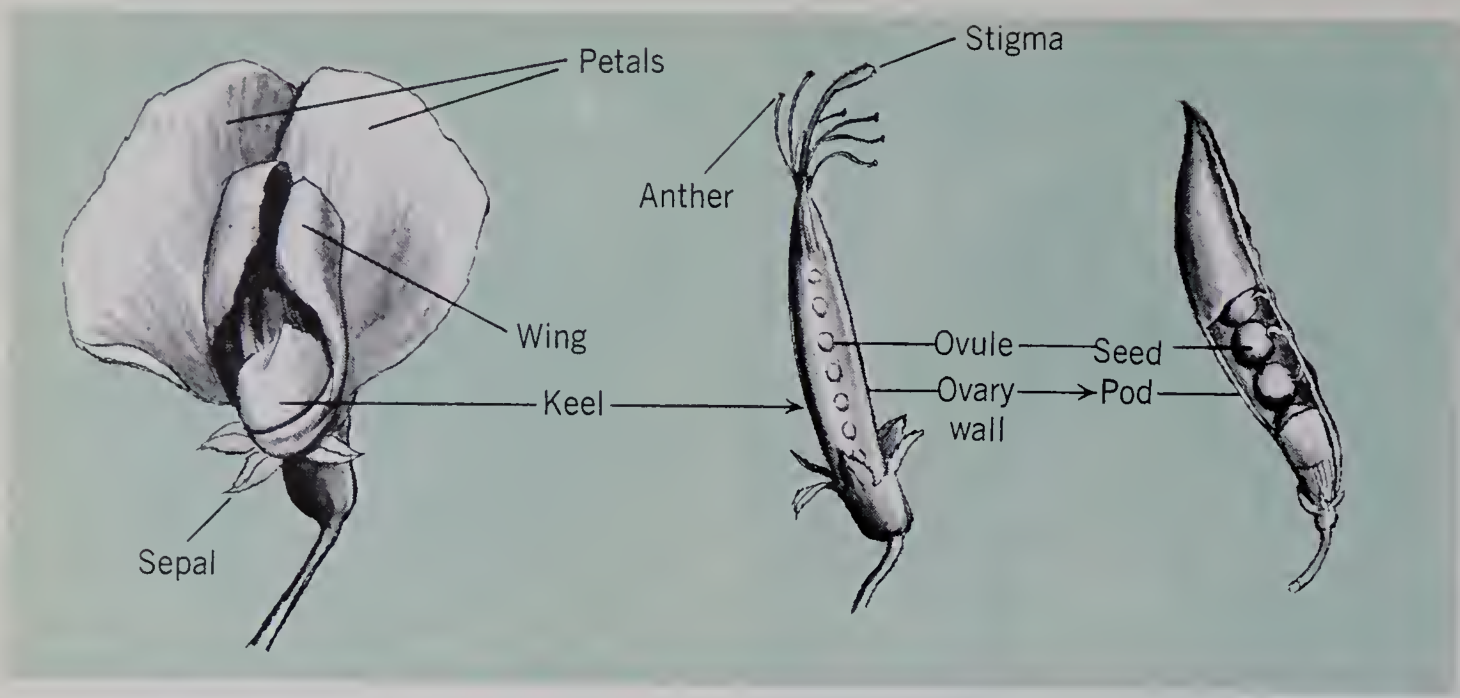
Austria. Mendel had been dead for 16 years when three other scientists discovered his work and began to make use of his findings. It is, however, a great tribute to Mendel that the laws he formulated from his experiments with garden peas stand today, practically unchanged, as the basis of the science of genetics. It is also very remarkable that his principles of inheritance were developed without a knowledge of chromosomes and their behavior.

During his years as a teacher in a high school in Brünn, Mendel kept a small garden plot at the monastery where he lived. He used several kinds of plants for his experiments, but the work for which he is remembered are the experiments he conducted with the garden peas. Why did Mendel choose garden peas for his experiment? First, he had observed that they differed in certain definite characteristics. Some plants were short and bushy, while others were tall and climbing. Some produced yellow seeds, some green seeds; some had colored seed coats and some white. Mendel identified seven different pairs of traits in which the plants differed consistently.

In order to understand the second reason why Mendel found garden peas ideal for his experiments, you will need a brief introduction to reproduction in the seed plants. You are probably familiar with the fact that the flower is the reproductive structure in seed plants. The flowers of pea plants bear male structures called stamens, which produce pollen grains which form sperm, and female structures called pistils, which contain egg cells at their base. The transferring of pollen from stamens to pistil, before fertilization occurs, is called pollination. Pea plants normally carry on self-pollination, which means that pollen is transferred from stamens to pistil on the same flower or another flower of the same plant. Cross-pollination involves flowers on two different plants.

Mendel found that cross-pollination could be performed easily in pea plants. He could accomplish this by removing the stamens from a flower so that self-pollination and self-fertilization could not occur. He then transferred flower pollen from one plant to the pistil of a flower of another plant. This flower was carefully protected from any pollen grains which might be transferred to it by wind or insects. Because of the pea's seven different characteristics, and because cross-pollination was easy to perform, Mendel had selected an ideal subject for breeding experiments.

Mendel discovers the principle of dominance. Mendel allowed several generations of peas to self-pollinate. He



9-2 The garden pea: flower, young fruit, mature fruit with seeds.

found that the seven characteristics he had identified were always handed down from parent to offspring. Seeds from tall plants produced other tall plants, and yellow seeds produced plants with yellow seeds. Mendel's next step was to see what would happen if he crossed two plants with contrasting traits. Accordingly he selected one tall parent and one short one. He made hundreds of crosses by transferring the pollen from the tall plants to the pistils of the short ones. When the seeds matured on the short plants, he sowed them to find out the results of his cross. Would the offspring be short like one parent, tall like the other, or of medium height with characteristics of both? He discovered that all the plants were tall, like the plant from which he had taken the pollen in making the cross.

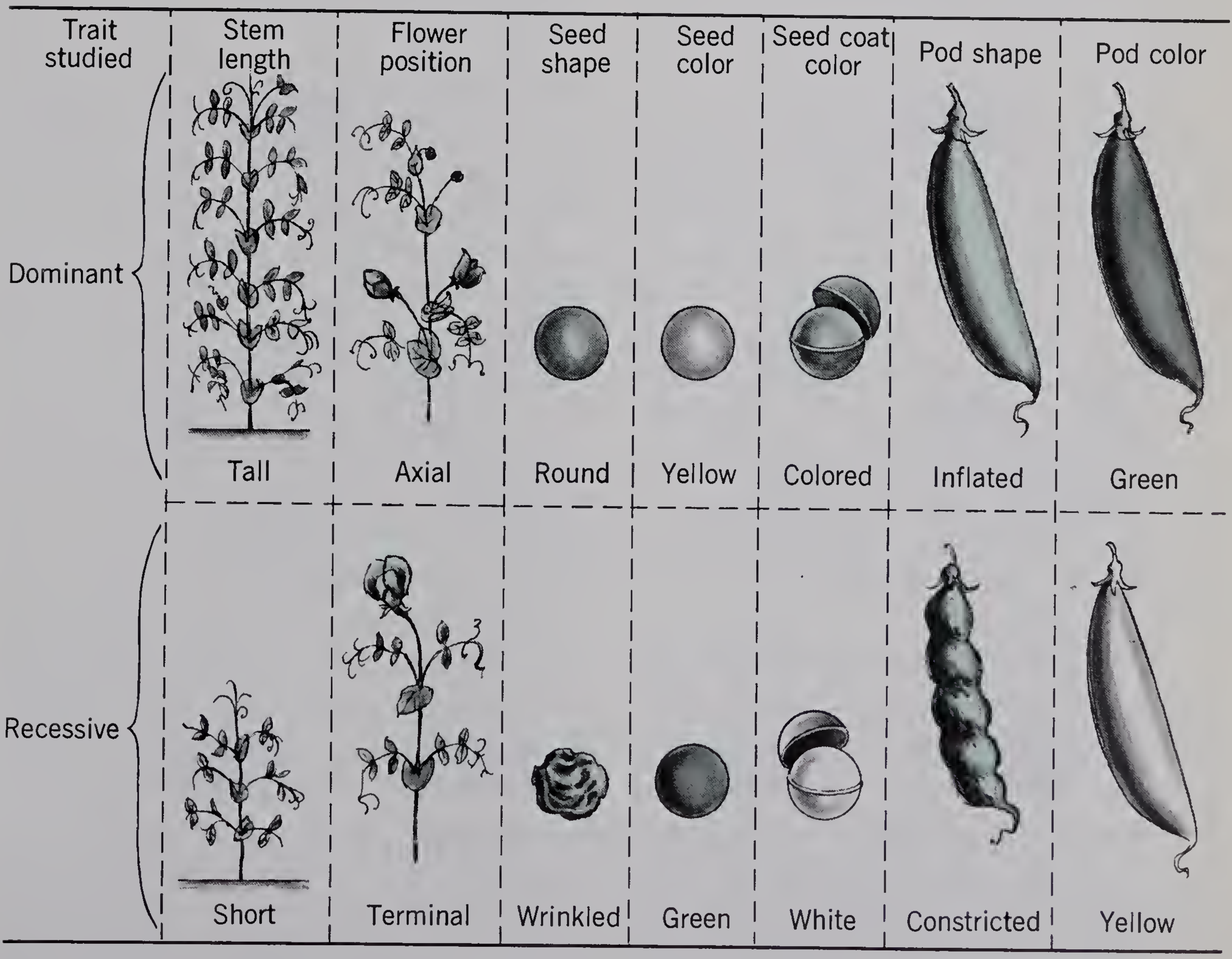
His next step was to determine if it made any difference which plant he used for pollen and which he used to produce the seeds. Accordingly he reversed the process of pollination, using a short plant for pollen and a tall one for seed production. Mendel found that the results were as before — all the offspring were tall.

Mendel then experimented with other characteristics. He limited his study of each cross to a single characteristic involving only *one* trait at a time. For example, he crossed plants contrasted in just one trait, such as yellow seeds and green seeds. He found that all of the first generation of the cross had yellow seeds. Similarly, he discovered that round-seeded varieties crossed with plants with wrinkled seeds produced a generation with round seeds. He repeated these crosses until he had tested the seven different characteristics. Mendel was surprised to find that in all seven crosses, one of the characteristics present in the parent plant seemed to be lost in the next generation. What would happen if he permitted these offspring to self-pollinate? This step in his experiment was destined to make history, since it led to the discovery of two important laws of heredity.

Mendel's conclusions relating to inheritance of traits were based on data accumulated from the study of a large number of offspring. He kept accurate record of all the crosses he made. In recording his generations of crosses, Mendel designated the *parent plants* used in the first cross as **P**. He referred to the generation resulting from this cross as the *first filial* or F_1 generation. By allowing the tall plants to self-pollinate, he produced a *second filial* or F_2 generation. The results of this self-pollination were quite striking. Some of the plants were tall while others were short. None were in-between. Furthermore, three fourths of the plants were tall, while one fourth were short. The reappearance of short plants in this generation was of great significance to Mendel. The F_1 plants had possessed a character for shortness without showing it.

When he permitted other F_1 generation plants to self-pollinate, he had the same results. When allowed to self-pollinate, the yellow peas that had been produced by crossing parent plants with yellow seeds and those with green seeds produced peas of which three fourths were yellow, and one fourth green.

Mendel's first laws of heredity. The fact that tall peas crossed with short peas produced an F_1 generation of tall peas and that short peas reappeared in the F_2 generation led Mendel to reason that something within the plant controlled a characteristic such as height. He called these unknown influences *factors.* Today we call them *genes.* He reasoned further that height in peas was controlled by a pair of factors, since some peas were short while others were tall. On this basis he formulated his first law of heredity, the ***law of unit characters.*** This law states that *the various hereditary characteristics are controlled by factors* (*genes*), *and that these factors occur*


Trait studied
Stem length
Flower position
Seed shape
Seed color
Seed coat color
Pod shape
Pod color
Dominant
Tall
Axial
Round
Yellow
Colored
Inflated
Green
Recessive
Short
Terminal
Wrinkled
Green
White
Constricted
Yellow

9-3 Mendel's seven pairs of contrasting traits in garden peas.

in pairs. Of course Mendel did not know about genes or chromosomes, which makes even more remarkable the fact that his law of unit characters is now a basic principle in genetics.

Mendel reasoned further that the tall plants of his F_1 generation were not like the pure tall parent plants. These peas were carrying a concealed factor for shortness that would reappear in the next generation. This reasoning led to the discovery of his second law of heredity, the ***law of dominance.*** This law states that *one factor (gene) in a pair may mask or prevent expression of the other.* Mendel gave the name ***dominant*** to the characteristic, such as tallness, that always appeared in the offspring of a cross between parents with contrasting characters. He referred to the characteristic, such as shortness, that did not appear in the F_1 generation but reappeared in the F_2 generation as ***recessive.***

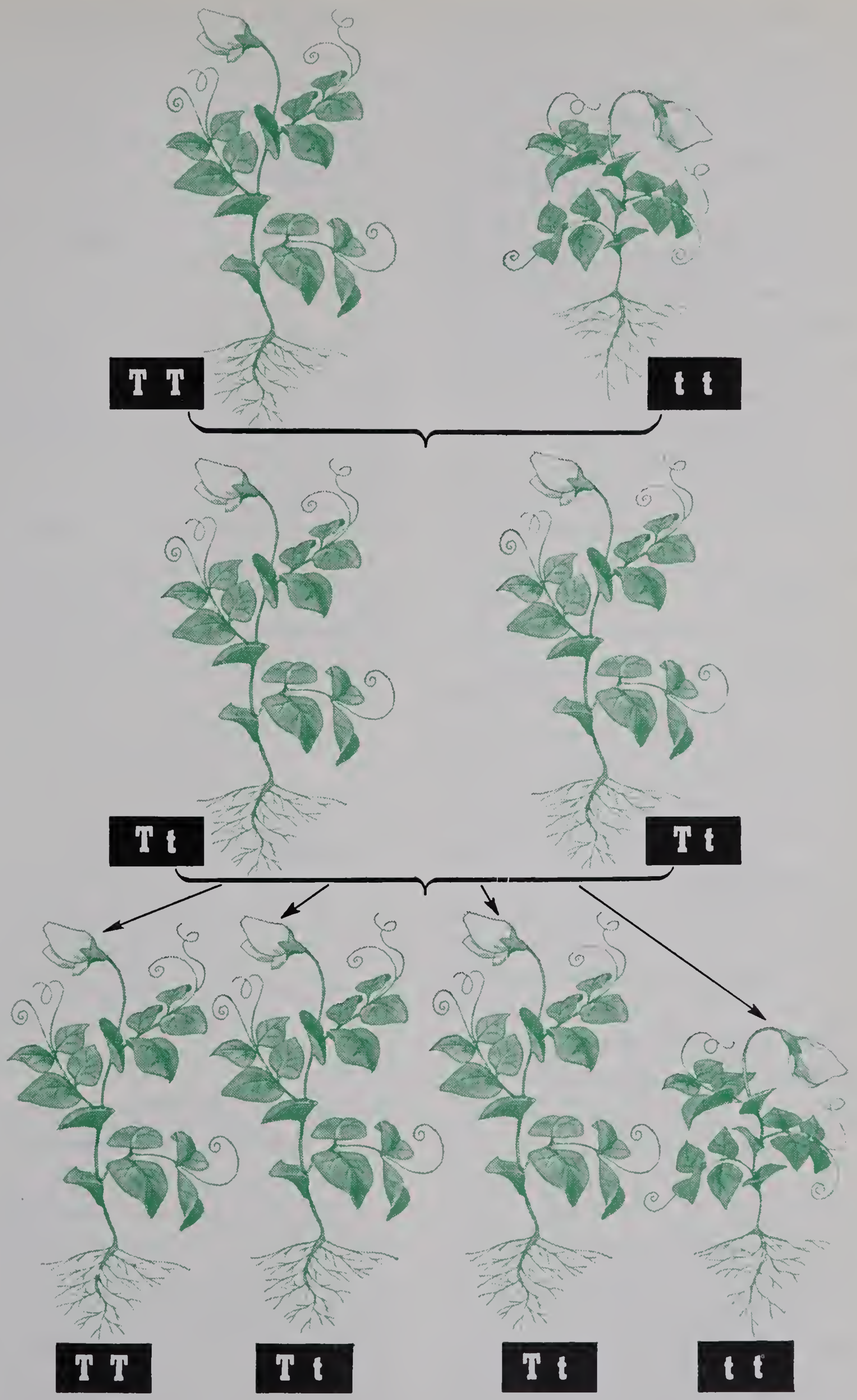
In Mendel's crosses one parent was pure tall, having both genes for tallness. The other was pure short, having both genes for shortness. The members of the F_1 generation were all tall but were ***hybrid,*** a term we use to designate the offspring of a cross between two parents that differ in one or more traits. The members of this generation had one gene for tallness and one for shortness, but appeared tall because the gene for tallness was dominant over the one for shortness.

If we let the letter T stand for tall, a pure tall plant would be written TT, indicating that both its genes for this character were for tallness. The capital T indicates that tallness is dominant over the contrasting character, shortness. In like manner, the small letter t stands for short, and a pure short individual would be designated as tt.

You learned in Chapter 8 that all body cells contain the diploid number of chromosomes. That is, chromosomes are present in *pairs* in these cells. Sex cells, on the other hand, contain the haploid number of chromosomes, having *only one member of each pair.* Remember that genes are located on chromosomes. Consequently, the egg cell in the female organ of the pea plant and the sperm formed by the pollen grain have only one gene for each character. When eggs or sperm are formed by a pure tall pea plant, one sperm receives one T and the other receives the other T. In like manner the tt genes present in all body cells of a pure short plant are separated in reduction division to t and t in the formation of eggs or sperm. During fertilization, each parent thus contributes one member of each pair of genes, and the diploid number is restored.

Mendel's law of segregation. Mendel based his third law of heredity, referred to as the ***law of segregation,*** on this reasoning. According to this law, *a pair of factors (genes) is segregated, or separated, during the formation of gametes (spores in lower plants) in reduction division.* That is, a gamete contains only one gene of a pair, the other having gone to another gamete. Furthermore, the composition of one gene is not altered by the presence of another gene in a pair. For example, a recessive gene in a hybrid is not altered by the presence of a dominant gene. If, in an offspring of the hybrid, the recessive gene is paired with another recessive gene, the recessive character will reappear (Fig. 9–4).

Some genetic terms. The genes of any organism can be designated by paired symbols for any characteristic you are studying. These symbols indicate the ***genotype*** of the organism. The effect



9-4 Mendel's law of segregation. Note that although the F_1 generation in this cross consists only of tall plants, the recessive gene responsible for shortness reappears in the F_2 generation and produces plants in the ratio of three fourths tall to one fourth short. What kind of plants would result from a cross between the two F_2 plants shown at the bottom left? Give the probable ratio of tall plants to short plants and the genetic make-up of each type.

of genes in an individual is described as its ***phenotype.*** It refers to the organism's size, color, structure, and other characteristics. For example, in hybrid tall peas, the genotype is *Tt;* its phenotype is tall. If the paired genes for a particular trait are identical, we call the organism ***homozygous*** (hoh-moh-*zy*-guhs) for that trait. An organism having different gene pairs is called ***heterozygous*** (*het*-e-roh-*zy*-guhs). The alternative forms of a gene are called ***alleles*** (a-*lee*-elz). Some genes may have as many as 100 alternative alleles. In the gene pair *Tt, T* is an allele of *t; t* is an allele of *T*. In the gene pair *Yy,* Y is an allele of *y; y* is an allele of Y. But *T* is *not* an allele of Y. The separation of alleles during reduction division demonstrates Mendel's law of segregation.

Method of diagramming Mendel's crosses. In the study of genetics we use special charts resembling checkerboards to determine the possible results of various crosses. This grid system is called a ***Punnett square*** after R. C. Punnett, who devised it. The gametes formed by the female are shown across the top of the grid. Gametes formed by the male parent are shown along the side. You can determine all possible combinations of the gametes by filling in the squares of the grid. Mendel's work with peas can be shown more clearly by diagramming his crosses on grids such as those that follow in this chapter. In working the grids just "cross-multiply" each gamete and fill in the correct offspring.

The monohybrid cross. When one pair of characteristics in an individual is crossed, the individuals possessing mixed genes are called ***monohybrids.*** A cross between a homozygous tall (*TT*) and a homozygous short (*tt*) pea plant is diagrammed as follows:

RESULTS OF CROSSING
TT AND tt

Female → GENES Male ↓	t	t
T	Tt	Tt
T	Tt	Tt

All of the offspring are monohybrids, with the genotype *Tt.* However, they appear equally as tall as the tall parent plant because the gene for tallness is dominant to the gene for shortness.

If the heterozygous *Tt* plants are permitted to self-pollinate, it is easy to see that four combinations of genes may occur, as shown in the following grid:

RESULTS OF CROSSING
Tt AND Tt

Female → GENES Male ↓	T	t
T	TT	Tt
t	Tt	tt

The grid also shows how the genes *T* and *t* from the heterozygous parents, though they combine by chance, result in offspring that are one-fourth pure dominant (*TT*), one-half hybrid (*Tt*), and one-fourth pure recessive (*tt*). This may be expressed as a ratio of 1:2:1, which states that the expected ratio of the genotypes is one-fourth pure tall, one-half hybrid tall, and one-fourth pure short. Another way to express the result is by phenotypes, which would be expected to occur in a ratio of 3:1 — three tall plants to every one short plant.

RESULTS OF MENDEL'S MONOHYBRID CROSSES

P_1 *Cross*	F_1 *Plants*	F_2 *Plants*	*Ratio*
Round × wrinkled seeds	All round	5,474 round 1,850 wrinkled	2.96:1
Yellow × green seeds	All yellow	6,022 yellow 2,001 green	3.01:1
Red flowers × white flowers	All red	705 red 224 white	3.15:1
Inflated pods × constricted pods	All inflated	882 inflated 299 constricted	2.95:1
Green pods × yellow pods	All green	428 green 152 yellow	2.82:1
Axial flowers × terminal flowers	All axial	651 axial 207 terminal	3:14:1
Long stem × short stem	All long	787 long 277 short	2.84:1

The same scheme explains the ratios resulting from other crosses. The cross between a heterozygous tall (*Tt*) and a homozygous tall (*TT*) pea plant will give the ratios shown in the grid that follows. The phenotype of all the plants is tall.

RESULTS OF CROSSING TT AND Tt

Female → GENES Male ↓	T	t
T	TT	Tt
T	TT	Tt

We can also determine the expected results from the cross between a homozygous short (*tt*) and a heterozygous tall (*Tt*) pea plant. The ratio of the phenotype is one-half tall to one-half short plants; the ratio of the genotypes is one-half *Tt* to one-half *tt*, as shown in the following grid.

RESULTS OF CROSSING Tt AND tt

Female → GENES Male ↓	t	t
T	Tt	Tt
t	tt	tt

The results that Mendel obtained with two generations of garden peas are listed in the table at the top of the page.

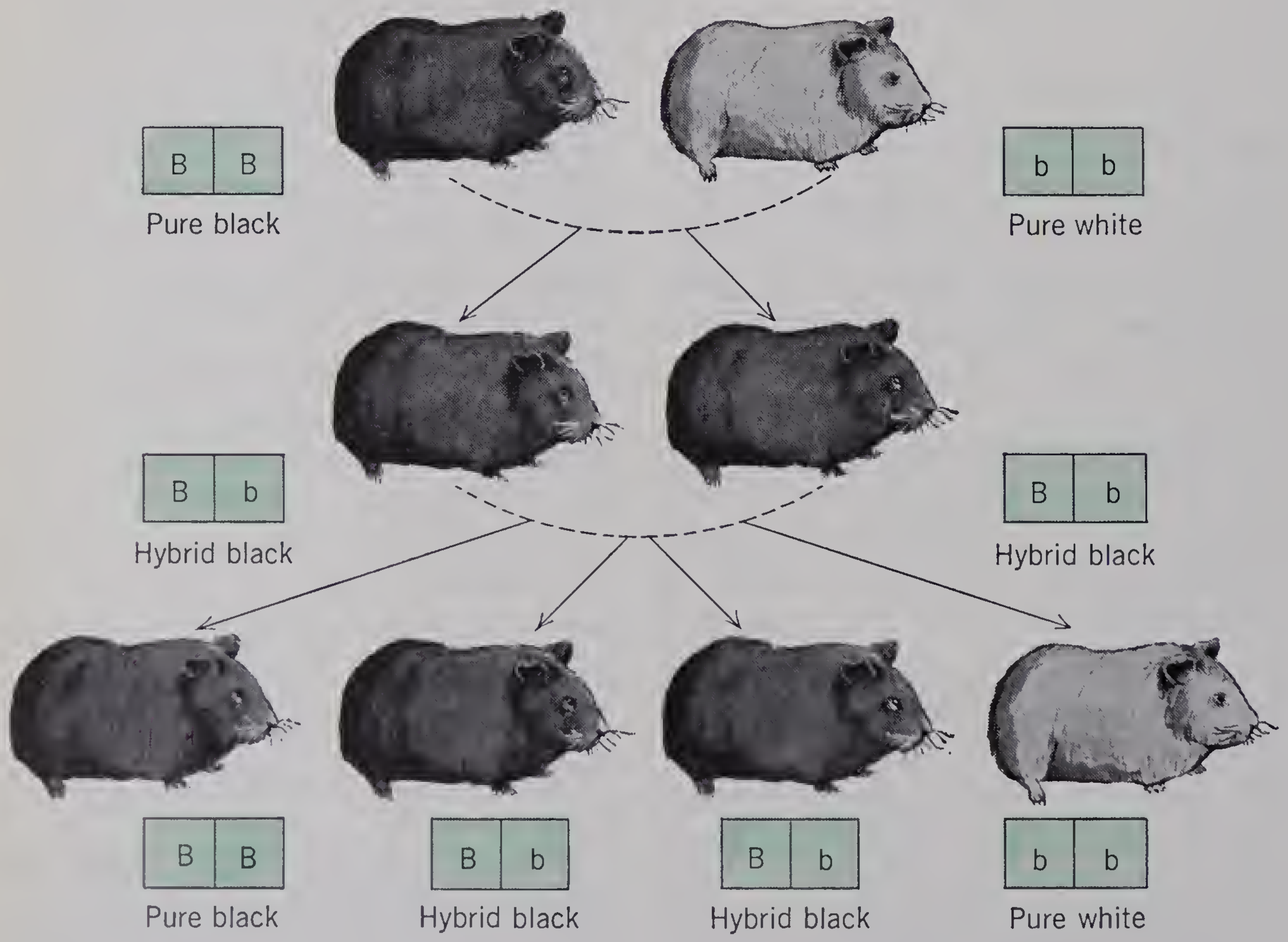
Dominant and recessive genes in guinea pigs. The same results Mendel obtained in crossing tall and short peas are shown in the inheritance of coat color in guinea pigs. In these animals the color black is dominant to white.

Let's see what happens when we cross a homozygous black guinea pig with a homozygous white one. All of the F_1 generation will be heterozygous black. In order to determine whether the animal is carrying a recessive gene for white, we can cross two of the offspring. The expected ratio of the offspring of this cross is one-fourth homozygous black, one-half heterozygous black, and one-fourth homozygous white. If only one animal shows the recessive trait, we have demonstrated that the F_1 generation was heterozygous for white. The expected phenotype of the cross is three-fourths black and one-fourth white. The grid for the cross between the two heterozygous (*Bb*) offspring of the F_1 generation follows (see also Fig. 9–5):

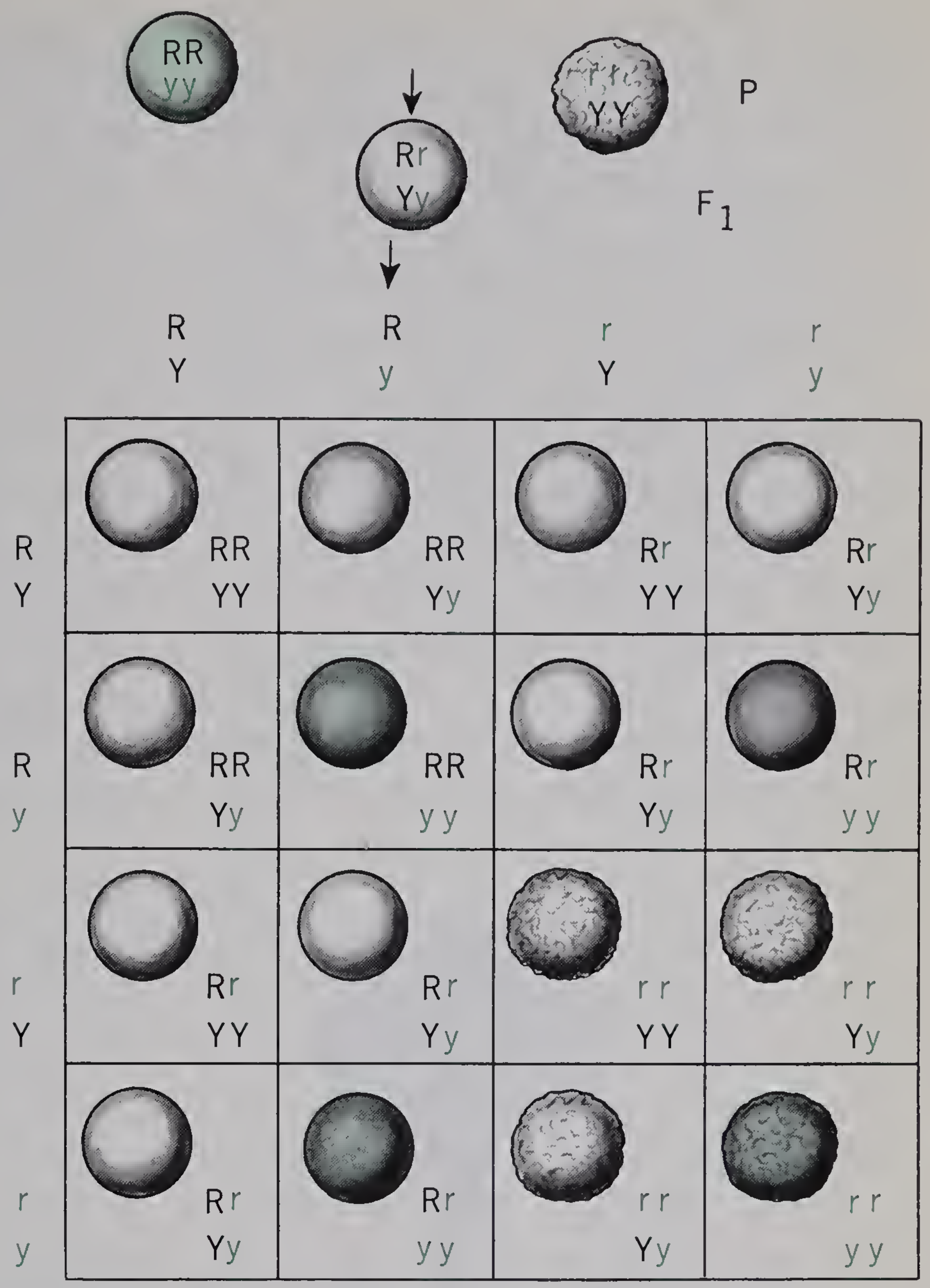
RESULTS OF CROSSING
Bb AND Bb

Female → GENES Male ↓	B	b
B	BB	Bb
b	Bb	bb

The same ratios occur after the crossing of rough-coated and smooth-coated guinea pigs. In the pair of alleles governing coat texture, the gene for rough coat is dominant over that for smooth coat.



9-5 The cross between a pure white guinea pig and a pure black one produces hybrid black animals in the F_1 generation. What results are obtained when these F_1 generation animals are crossed?



9-6 This Punnett square shows the various types of seeds that can result in the F_2 generation from a cross between a pea plant with round (*R*) and green (*y*) seeds and one with wrinkled (*r*) and yellow (*Y*) seeds. The possible female gene combinations are printed across the top of the square while the possible male gene combinations are printed down the left side of the square. Dominant genes appear in black; recessive ones in color.

Crosses involving two characters. Crosses involving two characters become more complicated than simple crosses in which only one pair of contrasting characters is considered. The same principles apply, but the possible gene combinations are increased. When two pairs of characteristics are involved, the individuals possessing mixed genes for both characters are called ***dihybrids.***

If a pea with round green seeds (two characters) is crossed with a pea having wrinkled yellow seeds, all members of the F_1 generation have round and yellow seeds. The recessive characters of green color and wrinkled seed coat are overshadowed by the two dominant traits. In this cross *R* will stand for a gene for round seed coat, *r* for wrinkled, Y for yellow color, *y* for green. The F_1 dihybrids would all have the genotype *RrYy*,. a gene for round seed coat (*R*) having come from one parent, and a gene for wrinkled (*r*) having come from the other. In like manner one parent supplied a gene for yellow color (Y), while the other supplied a gene for green (*y*).

When the two dihybrid round yellow peas are crossed, the situation becomes more complicated. Each dihybrid with the genotype *RrYy* may produce four kinds of eggs or sperm. During reduction division the pairs *R* and *r* as well as Y and *y* must separate and go into different cells. *R* may pair with Y to form *RY* or *R* may pair with *y*, resulting in *Ry*. Similarly *r* may pair with

Y to form *rY* or with *y* to form *ry*. The nature of the offspring in such a cross depends on which eggs and sperm happen to unite during fertilization.

The possible offspring that may result from such a cross and the ratio of their occurrence may be diagrammed as in the crossing of a single contrasting character, except that space must be provided for more possible crosses. Figure 9–6 shows the result of such a cross. One of the parents was pure round green (*RRyy*), while the other was pure wrinkled yellow (*rrYY*). You will note that all the F_1 generation are alike, being dihybrid round yellow (*RrYy*). In the F_2 generation, however, four different phenotypes have been produced, as follows:

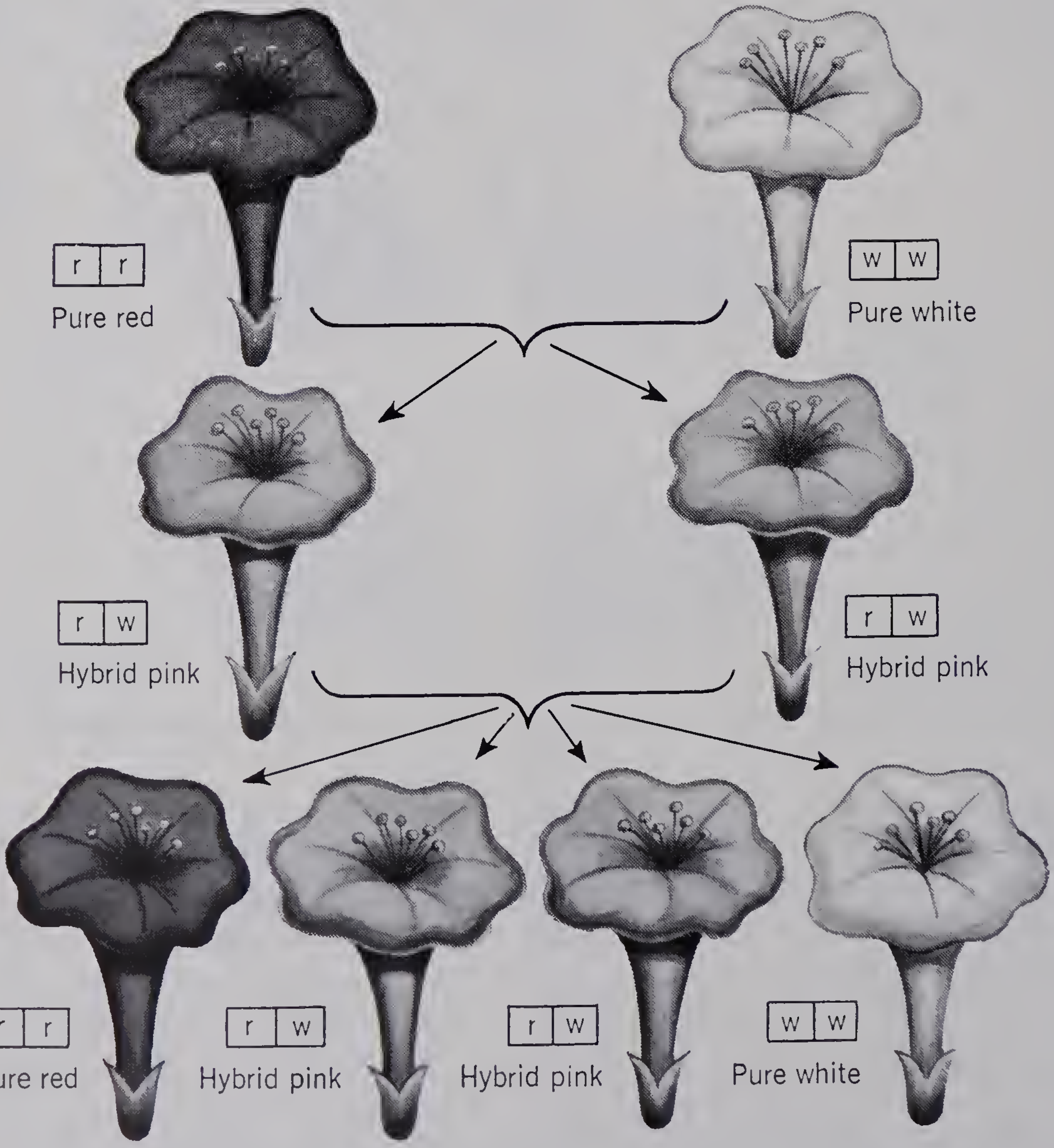
9⁄16 of the offspring have seeds that are round and yellow (both dominant traits).

3⁄16 have seeds that are round and green (one dominant and one recessive trait).

3⁄16 have seeds that are wrinkled and yellow (the other dominant and the other recessive trait).

1⁄16 has seeds that are wrinkled and green (both recessive traits).

Notice that these four phenotypes occur in an expected ratio of 9:3:3:1.



9-7 Incomplete dominance in four-o'clock flowers.

You will note, also, that the genotypes show that yellow seeds may be either pure yellow or hybrid yellow; also that round seeds may be either pure round or hybrid round. A recessive character only shows when both genes for the recessive character are present. Both recessive characters appeared only once in the 16 possibilities.

When heterozygous black, rough-coated guinea pigs are crossed (genes for black and rough are dominant), similar results can be expected: $9/16$ of the offspring are black and rough, $3/16$ are black and smooth, $3/16$ are white and rough, and $1/16$ is white and smooth.

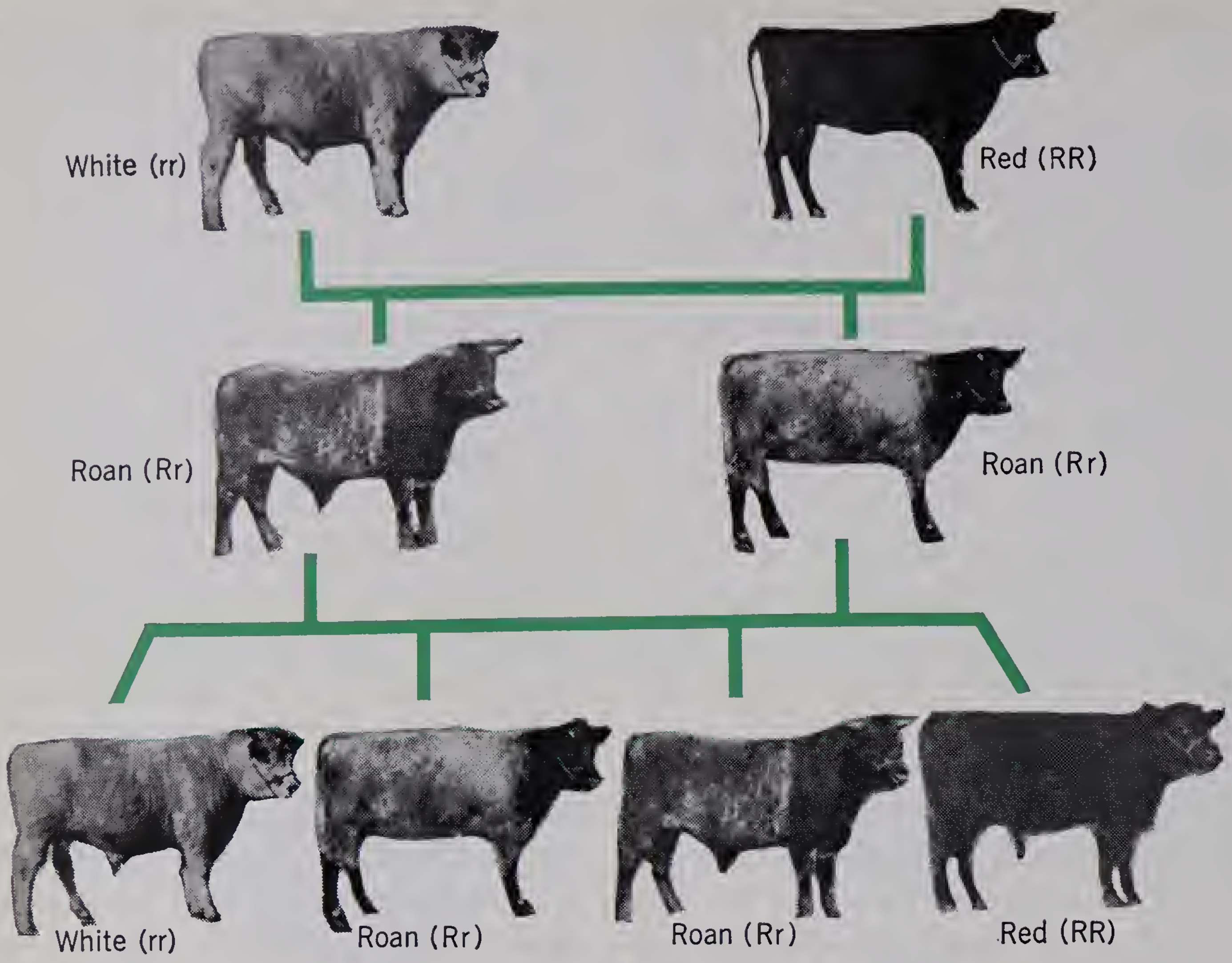
The law of independent assortment. The dihybrid crosses you have studied illustrate another of Mendel's laws, the ***law of independent assortment.*** According to this law, *the separation of gene pairs on a given pair of chromosomes and distribution of the genes to gametes (spores in lower plants) during reduction division is entirely independent of the distribution of other gene pairs on other pairs of chromosomes.* This law applies only when genes are on different chromosome pairs, since it is chromosomes and not genes that assort independently.

Incomplete dominance. Genes are not always dominant or recessive. In some characteristics, both alleles of a pair may be expressed. This ***incomplete dominance,*** as it is called, may be illustrated in crossing the flowers of four-o'clocks and snapdragons. When pure red four-o'clocks (*rr*) are crossed with pure white (*ww*) varieties, all of the first generation are pink (*rw*). Neither red nor white is completely dominant, so that both colors are expressed in the heterozygous F_1 offspring as pink. However, when two of these heterozygous pink (*rw*) flowers are crossed, the F_2 generation includes one-fourth red, one-half pink, and one-fourth white individuals. The fact that genes for red and white actually did not mix in the pink offspring is indicated in the fact that both pure characteristics appear again in the second generation (Fig. 9–7).

Similarly, the color of Shorthorn cattle illustrates incomplete dominance. A homozygous red animal mated with a homozygous white animal produces a blend of red and white called *roan* offspring. When two roan animals are mated, the expected ratio of the offspring would be one-fourth red, one-half roan, and one-fourth white, illustrating again the 1:2:1 ratio (Fig. 9–8).

Ratios are based on averages. The ratios obtained in breeding experiments represent *averages* and not definite numbers that will always appear. These ratios are accurate *only when large numbers of individuals are considered.* For example, two roan shorthorns bred four times will not necessarily produce one red calf, two roan ones, and a white one. Two heterozygous black guinea pigs will not always produce one homozygous black, two heterozygous blacks, and one homozygous white. If only four eggs and four sperm were involved in the process, the ratio would work out. But actually the eggs may be more or less than four in number, and the sperm usually number in the millions. Thus it is a matter of chance as to how the eggs and sperm will unite.

Chance ratios may be shown with two coins. When you flip them, they will light in these possible combinations: two heads, one head and one tail, or two tails. There is twice the chance of one head and one tail appearing as two heads or two tails. One of the reasons for the great accuracy of Men-



9-8 Incomplete dominance in Shorthorn cattle.

del's work with the peas is due to the fact that he used such large numbers of plants.

Application of Mendel's laws to other organisms. Scientists have worked with numerous traits of plants and animals, and have shown that the truth of the Mendelian laws is beyond question. There is overwhelming evidence that inheritance in human beings also follows the Mendelian laws. In the chapters to follow we shall discuss several examples of Mendelian genetics in man.

IN CONCLUSION

Heredity and environment are the two important forces that interact to control our individual make-up. Hereditary traits are produced by genes, which are contained in chromosomes. Although Mendel knew nothing of genes or even chromosomes, his work before the turn of the century gave us the basis for our modern understanding of genetics.

The genius of Gregor Mendel was his discovery that variations appeared in an orderly manner. Laws seemed to control the heredity of those peas — laws so exact that he could predict the kind of peas the seeds would produce. We have gone far beyond Mendel, but we have never revised our understanding of his laws.

As you continue your study of genetics, you will learn more about chromosomes, gene structure, and the mechanics of gene action.

BIOLOGICALLY SPEAKING

allele
dihybrid
dominant trait
environment
F_1 generation
F_2 generation
genetics
genotype
heredity
heterozygous
homozygous
hybrid
incomplete dominance
individual characteristic
law of dominance
law of independent assortment
law of segregation
law of unit characters
monohybrid
P generation
phenotype
Punnett square
recessive trait
species characteristic

QUESTIONS FOR REVIEW

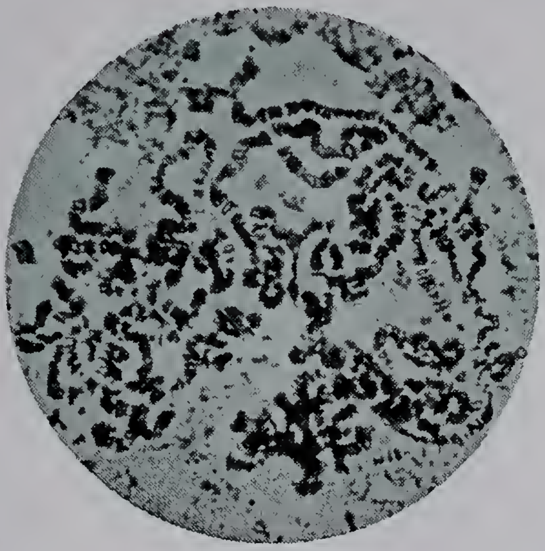
1. What is the relative importance of hereditary and environmental characteristics?
2. Why did Mendel choose garden peas for his experiments?
3. List seven pairs of contrasting traits Mendel found in garden peas. Which of these traits are dominant?
4. Why did Mendel limit each cross to a single characteristic?
5. The gene for black coat color is dominant in guinea pigs. How is a homozygous black different from a heterozygous black, even though the guinea pigs look alike?
6. When two hybrid animals are crossed, homozygous dominant, heterozygous dominant, and homozygous recessive individuals appear. Account for this.
7. When two parents that are heterozygous for one character are crossed, what ratio of offspring (F_1 generation) are expected to show the dominant character and what ratio the recessive character?
8. Explain the law of independent assortment.
9. In what way is incomplete dominance an exception to the law of dominance?
10. In breeding experiments, why do the ratios obtained represent averages rather than definite numbers?

APPLYING PRINCIPLES AND CONCEPTS

1. Outline a possible cross to determine whether a black guinea pig is homozygous or heterozygous for the coat-color trait.
2. In guinea pigs, black coat color is due to a dominant gene, *B*, and white is due to its recessive allele, *b*; short hair to a dominant gene, *S*, and long hair to its recessive allele, *s*. The gene for rough coat, *R*, is dominant to that for smooth, *r*. Cross a homozygous rough, short-haired black guinea pig with a smooth, long-haired white one. What are the phenotypes of the F_1 and F_2 generations?

3. In snapdragons the inheritance of flower color and size of leaves are examples of incomplete dominance. When red-flowered plants are crossed with white ones, all the flowers are pink. Similarly, when plants with broad leaves are crossed with plants having narrow leaves, the offspring have intermediate leaves. Cross a homozygous red-flowered, broad-leaved plant with a homozygous white-flowered, narrow-leaved plant. What kind of offspring are produced in the F_1 generation? Now cross two of these plants and find the phenotype ratio of the offspring. Explain the relationship of the 9:3:3:1 ratio to the one you obtained.
4. Why should a hybridizer know which traits in plants or animals with which he is working are dominant or recessive?
5. Why does the law of independent assortment apply only to certain pairs of genes?

CHAPTER 10



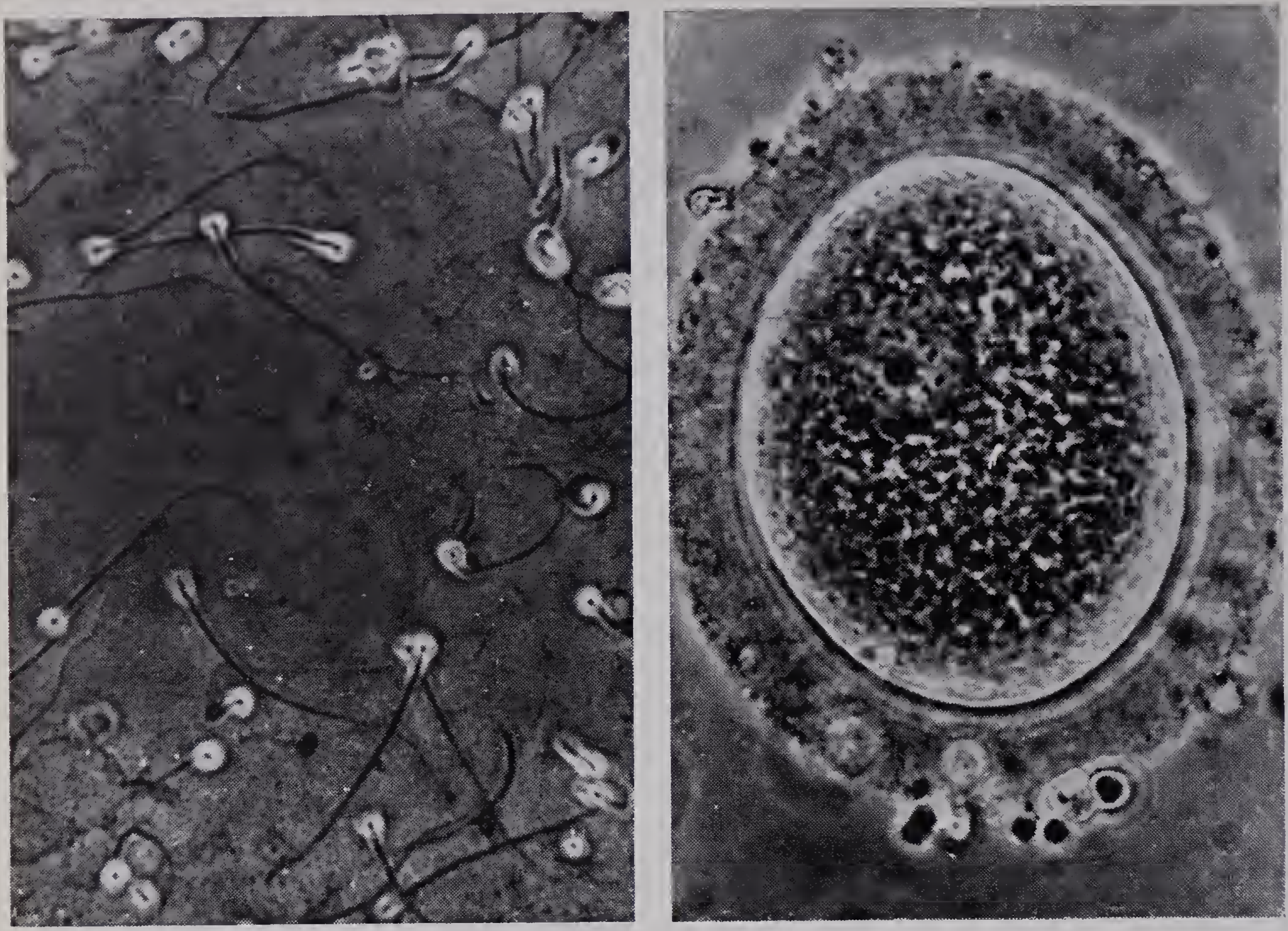
THE GENETIC MATERIAL

The chromosome theory of inheritance. The work of Gregor Mendel seems even more remarkable when you consider that he made his brilliant observations, drew valid conclusions, and formulated his laws without any knowledge of genetic materials. It was 20 years after publication of his paper that the cell nucleus was recognized as the center of hereditary materials. Mendel knew nothing about reduction division and segregation of chromosomes during meiosis. In fact he never heard of a chromosome. Yet he formulated his law of segregation on the basis of what he observed in crossing garden peas. Mendel described *what* happened in various genetic crosses without any idea of *why* they occurred.

A few years after Mendel published his studies of garden peas, biologists began searching for evidence of hereditary information in a cell. The nature of sexual reproduction, in which an egg and a sperm unite during fertilization, was known to biologists at this time. Furthermore, it was evident that each new individual produced by sexual reproduction bore characteristics of both parents. It was evident that these characteristics were transmitted to the offspring by means of certain factors contained in the egg and sperm. Is the entire content of the egg and the sperm involved in this hereditary influence? If this were true, the egg should exert the greater influence since it is often much larger than the sperm. Do the egg and sperm contribute equally to the genetic makeup of the new individual? What properties do an egg and a sperm have in common that might account for this equal influence? The most obvious similarity is the nucleus in each. These cell structures are of approximately equal size in an egg and a sperm. Could the nucleus, then, contain the genetic information? If this were true, an egg or a sperm must contain only half of the genetic material of the organism. Otherwise, this material would be doubled in fertilization.

Questions such as these were being asked by biologists in the 1880's. It was during this time that August Weismann, a German biologist, suggested that reduction divisions occurred in the formation of eggs and sperm and predicted that biologists would soon discover how the process occurred. His prediction was soon fulfilled. About one year later, Theodor Boveri, a German biologist, actually observed meiosis in the cells of *Ascaris* (*as*-ka-ris), a common parasitic roundworm.

It is ironic that, during these years of searching for proof of reduction division, Mendel's paper containing the evidence for his law of segregation lay forgotten in the library of the Natural



10-1 These photomicrographs of human sperm and an ovum show the cells greatly magnified. (L. B. Shettles)

History Society of Brünn, Austria. Then in 1900 three biologists, working independently in the area of cell reproduction and heredity, were searching scientific libraries for information related to their problem. One was an Austrian biologist, Von Tschermak; another, De Vries, a Dutch botanist; and the third, Correns, a German botanist. All three of these men found copies of Mendel's paper in the library in Brünn. After 34 years of oversight, his work was finally rediscovered and put to use. By this time biologists were familiar with chromosomes and believed that they carried hereditary information. Mendel's paper supplied evidence of their function. This was the information needed to start a landslide of investigation and discovery in genetics.

The gene hypothesis. In 1903, just three years after the rediscovery of Mendel's paper, Walter S. Sutton, a young graduate student at Columbia University in New York, presented a hypothesis of great significance. In a research paper published in the *Biological Bulletin*, he proposed that hereditary particles, or genes, are component parts of chromosomes. This was the first reference to the gene as the determiner of a genetic characteristic.

In examining Mendel's work, Sutton found a striking similarity between the behavior of genetic traits of garden peas he described and the behavior of chromosomes during meiosis. Mendel had proposed the segregation of genetic traits in the formation of gametes. Sutton was familiar with the segregation of chromosomes during meiosis. This parallel led Sutton to the conclusion that chromosomes contained the material of heredity.

Furthermore, Sutton was familiar with Mendel's reciprocal crosses in garden peas. You will recall that Mendel reversed many of his crosses to see if it made a difference in the offspring if a parent plant was used to bear seeds in one cross and to supply pollen in another. In all these crosses the results were the same. Both parents contributed equally to the offspring. Sutton knew that eggs and sperm are not alike in size or in structure, but he found likeness in their chromosomes. This provided further evidence that chromosomes bear the particles that determine hereditary characteristics. Furthermore, he reasoned that these determiners, or genes, must be situated in identical positions on corresponding chromosomes, a belief later found to be true.

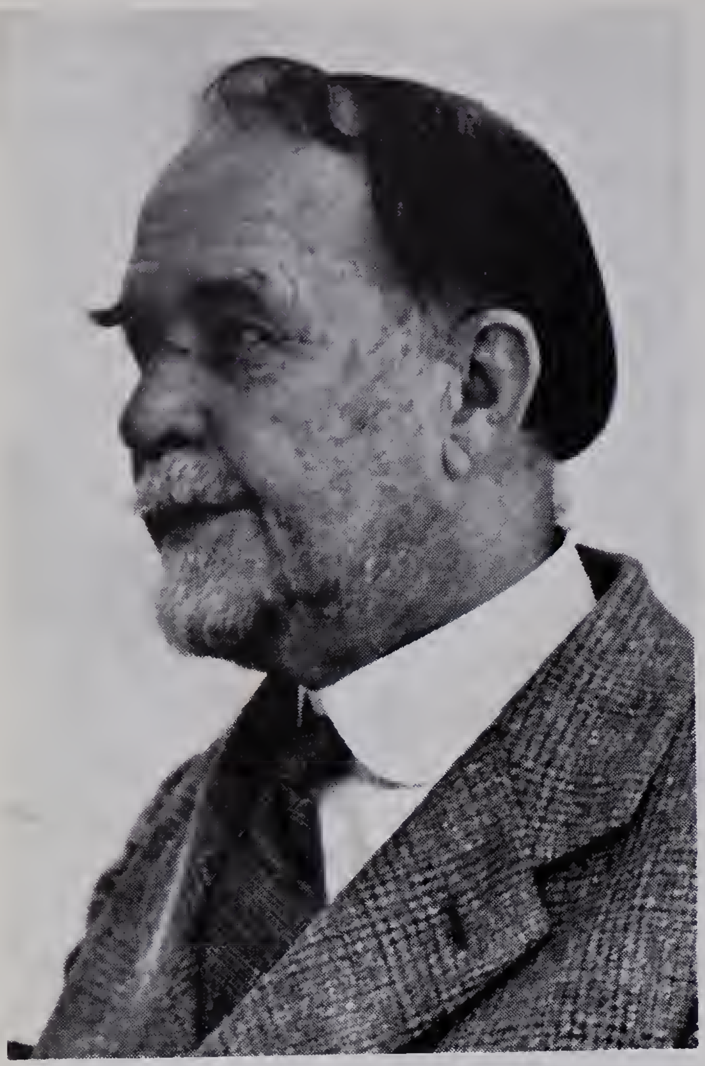
Sutton reasoned further that chromosome pairs maintain their identity with each division of a somatic, or body, cell of an organism. In these divisions segregation does not occur. All chromosomes split lengthwise, thus providing each daughter cell with identical genetic material. This occurs in mitosis, a process of cell reproduction which you have already studied.

Generally Sutton found three parallels between Mendel's hereditary factors and the behavior of chromosomes and genes:

1. Chromosomes and genes occur in pairs in the zygote and in all somatic cells.
2. Chromosomes and genes segregate during meiosis, and only one member of each pair normally enters a gamete.
3. Chromosomes and genes maintain their individuality during segregation. Each pair segregates independently of all other pairs. This confirmed Mendel's law of independent assortment of the characteristics he observed in garden peas.

How many genes on a chromosome? Having established the gene hypothesis, Sutton's next question concerned the number of genes on an individual chromosome. If, for example, an organism had 10 pairs of chromosomes, would it not have more than 10 pairs of genes? Organisms certainly had many more inheritable characteristics than pairs of

10-2 Walter S. Sutton first proposed that hereditary particles are component parts of chromosomes. (V. A. McKusick)



10-3 The great American geneticist, Dr. Thomas Hunt Morgan, did pioneer work on the fruit fly which led to the explanation of sex determination. (California Institute of Technology)

chromosomes. Undoubtedly many genes were located on each chromosome. It seemed unlikely to Sutton that genes segregated independently during meiosis. Rather, they must move in sets on a chromosome. In this explanation, Sutton proposed gene linkage. What, then, of Mendel's seven pairs of contrasting traits such as tall stem and short stem, round seeds and wrinkled seeds, yellow seeds and green seeds? Mendel based his law of independent assortment on the fact that all of the pairs of traits he studied segregated and recombined independently. Was a gene for each of these traits situated on a different chromosome or were certain genes linked on the same chromosome? Sutton believed that the genes involved in Mendel's studies must have been on different chromosomes since they segregated independently, although he could not prove this. Today we know that he was right in his assumption. The peas Mendel used had seven pairs of chromosomes. By coincidence each of the contrasting traits he studied was determined by genes on different chromosome pairs.

While Sutton believed that gene linkage must occur, he was never able to establish proof. However, a few years later, another great contributor to genetics found experimental evidence to support Sutton's brilliant deduction.

Discovery of sex chromosomes. Soon after Sutton established that chromosomes and genes are genetic materials, Thomas Hunt Morgan and a group of associates working at Columbia University made a discovery in one tiny fruit fly that was destined to make genetic history. Thomas Hunt Morgan was one of the pillars in the study of genetics. His genius was recognized when he was awarded the Nobel prize in medicine and physiology in 1933 for his research in genetics. Among his associates, all considerably younger, were three men who also made outstanding contributions in genetic research: Calvin Bridges, A. H. Sturtevant, and H. J. Muller. Dr. Muller was also awarded the Nobel prize in 1946 for outstanding work we shall discuss later in this chapter.

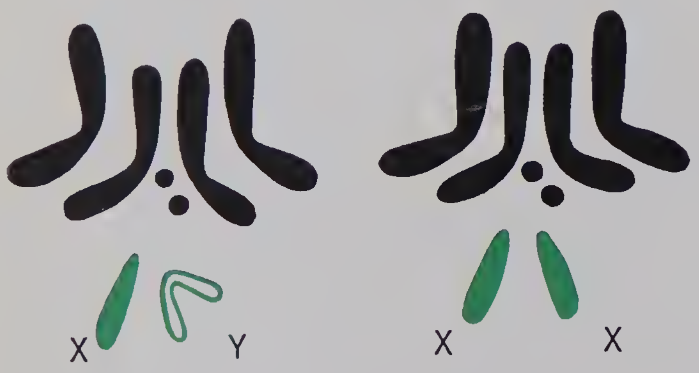
Dr. Morgan and his associates were growing large numbers of fruit flies in their studies of genetic traits at Columbia University. This small fly is common around overripe fruit. You probably think of it as a pest rather than a valuable subject for research in genetics. Biologists refer to the fruit fly

10-4 Left: a normal red-eyed female fruit fly; right: a normal red-eyed male. Note that the female is larger than the male and that the posterior end of the male is darker and blunter than that of the female. (Irwin I. Oster)

as *Drosophila melanogaster* (droh-*sahf*-i-la me-lan-oh-*gas*-ter), but we shall shorten its name to *Drosophila* here. Several characteristics of *Drosophila* make it an ideal subject for research in genetics. It is easily raised in jars containing mashed bananas and other specially prepared diets. The life cycle is short, varying from about 10 to 15 days, depending on the environmental temperature. Thus, many generations can be observed in a short time. Furthermore, the sexes of *Drosophila* are easily distinguished. The male is usually smaller than the female, has characteristic combs of dark bristles on its first pair of legs, and has a black-tipped, blunt posterior end. Genetic variations in *Drosophila* include eye color, body color, and wing structure. These are but a few of the thousands of variations in *Drosophila* with which geneticists are familiar today.

Now, to return to the one fruit fly that made genetic history. One day Dr. Morgan and his associates were examining a large number of *Drosophila* and, to their surprise, found one fly that had white eyes instead of the normal red eyes. The fly was a male. This unusual fly was mated with a normal red-eyed female. All of the F_1 generation resulting from this mating had normal red eyes. By applying Mendel's law of dominance, Morgan and his associates concluded that red eyes are dominant over white eyes in *Drosophila.* The investigation was continued with the mating of flies of the F_1 generation to produce an F_2 generation. About three quarters of these flies had red eyes, and about one quarter had white eyes. This, again, conformed to the results Mendel had obtained in garden peas that were hybrid, or heterozygous, for one trait. At this point Morgan made a significant discovery. All of the white-eyed flies were males! This could not be the result of chance. There was a definite association of eye color and sex. Morgan had discovered a sex-linked trait in *Drosophila*. Two problems had now arisen — sex determination in *Drosophila* and the relation of a gene for white eyes to the process. We shall now consider both of these problems.

Sex determination. At the time Dr. Morgan and his associates were experimenting with *Drosophila*, no one had examined the chromosomes of this fruit fly. This was the next step for Morgan and his associates in investigating the white-eyed male. Examination of the nuclei of somatic cells of *Drosophila* revealed four pairs of chromosomes. This is the diploid chromosome number. The cells of female flies contained four kinds of chromosomes with identical mates (Fig. 10–5). But there was a difference in the chromosomes of the male. Three pairs were like those of the female, but one chromosome was different. It did not match its mate. Instead of being rod-shaped, it was bent like a hook, or Y-shaped. The rod-shaped chromosomes are designated as X *chromosomes*, while the hook-shaped member of the pair is named the Y *chromosome*. These are the ***sex chromosomes***. The remaining three pairs in *Drosophila*, identical in both males and females, are designated as ***autosomes***.



10-5 The sex chromosomes of the fruit fly, *Drosophila*, are shown in color in this diagram. The female (right) has two straight X chromosomes. The male (left) has one straight X chromosome and one bent Y chromosome. In mating, combinations of X and X chromosomes produce females, while combinations of X and Y chromosomes produce male offspring.

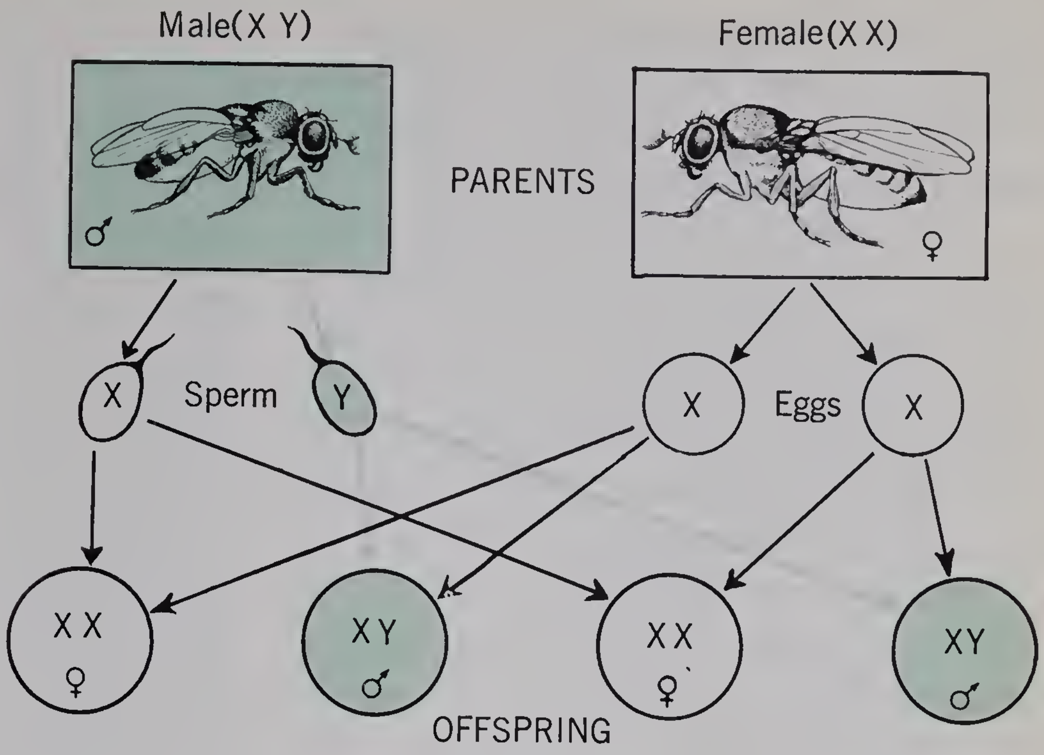
Following Morgan's fine work on sex chromosomes in *Drosophila*, studies were made of many other animals. Similar chromosomes were found in most animals and in many plants in which there is a sexual difference. The presence of two X chromosomes (XX) produces a female organism, while a single X chromosome paired with a Y chromosome (XY) results in a male.

Further study of sex chromosomes in many organisms has revealed a variation in what we might term XY sex determination. Some organisms have no Y chromosome in males. In these organisms XX produces a female, while XO results in a male.

It is easy to diagram sex determination by means of a grid, such as you used in showing Mendelian crosses involving a single trait. As we describe the formation of gametes and segregation of sex chromosomes, then fertilization and recombination of chromosome pairs, follow the changes shown on page 137. In the segregation of sex chromosomes in egg formation, the diploid number XX is reduced to the haploid number X. Thus, all eggs contain a single X chromosome. However, in the formation of sperm, the diploid number XY is reduced to X and Y. In other words half of the sperm contain the X sex chromosome and half the Y chromosome. The sex of the offspring is determined by the chance union of an egg and a sperm. If the X-containing sperm fertilizes the egg, the offspring is female. Union with a Y-containing sperm results in a male.

M

XYX^mX^m



10-6 The inheritance of sex in the fruit fly, *Drosophila melanogaster.*

SEX DETERMINATION		
Female CHROMOSOMES Male	X	X
X	XX	XX
Y	XY	XY

You may be interested in knowing that sex determination in human beings occurs in the same manner. Each of your somatic cells contains 23 pairs of chromosomes. Twenty-two of these pairs are autosomes. The remaining pair are sex chromosomes.

Sex linkage. Now that you are familiar with sex chromosomes and their function in the determination of sex, we shall return to a discussion of Morgan's white-eyed male flies. The crosses he made are diagrammed at the right and on page 138. Follow each step as it is described. We shall designate the gene for normal red eyes as *R* and use *r* to indicate white eye color. Both of these genes are situated on X chromosomes and are therefore sex-linked. The Y chromosome contains no functional DNA and therefore does not act in determining eye color in *Drosophila.*

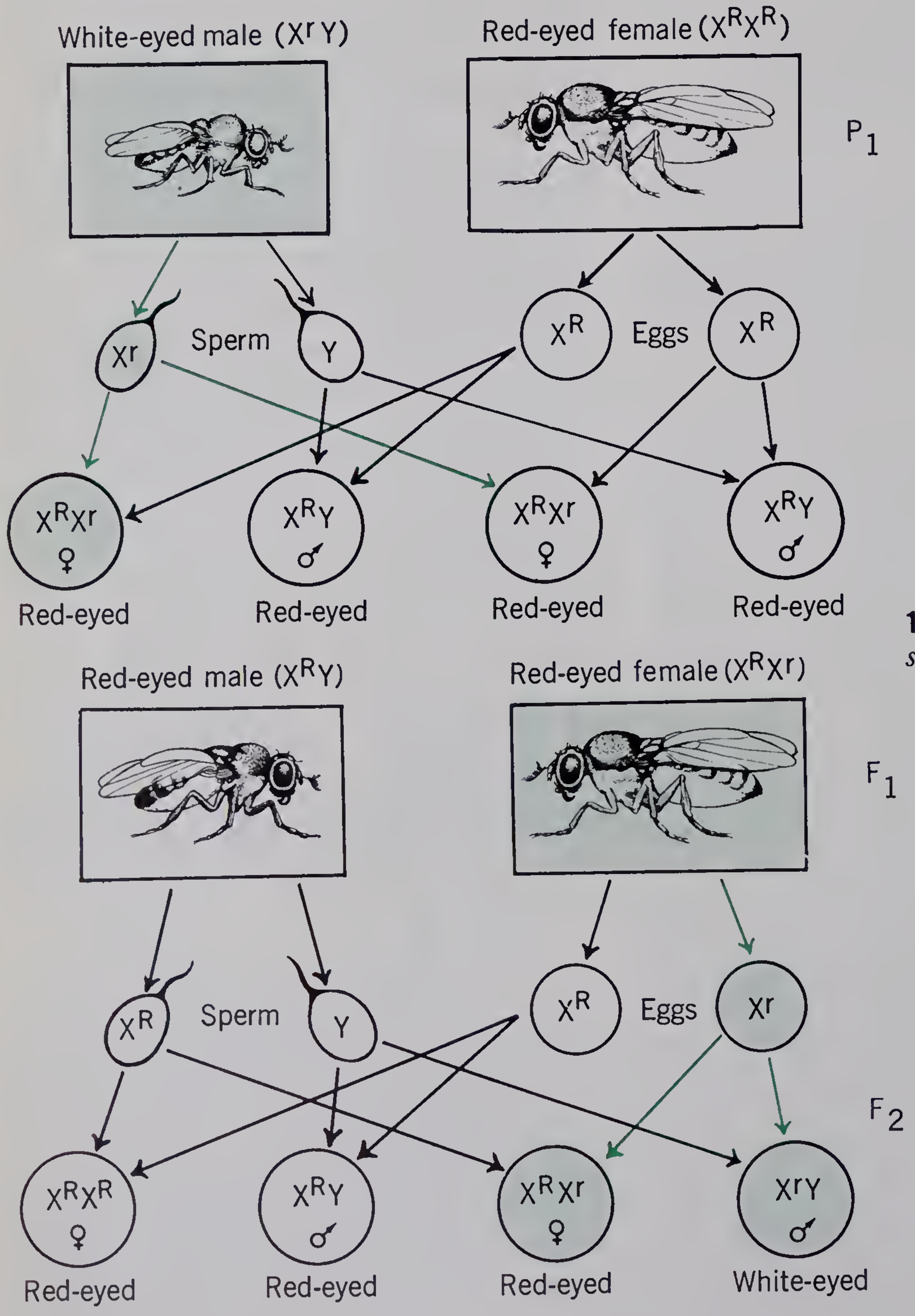
The original white-eyed male that Morgan discovered had a gene for white eyes on its X chromosome. We may represent this individual as X^rY. The normal red-eyed female, with a gene for normal red eyes, would be indicated as X^RX^R. As a result of segregation, the sperm formed by the white-eyed male would be of two types, X^r and Y. All of the eggs produced by the normal red-eyed female would contain X^R. All members of the F_1 generation would be red-eyed, although they would be of two genetic types. Eggs fertilized by half of the sperm would contain X^RX^r chromosomes and would be females, heterozygous for eye color. The other half would contain X^RY. These would

INHERITANCE OF SEX–LINKED CHARACTERISTICS		
Female SEX CHROMOSOMES Male	X^R	X^R
X^r	X^RX^r	X^RX^r
Y	X^RY	X^RY

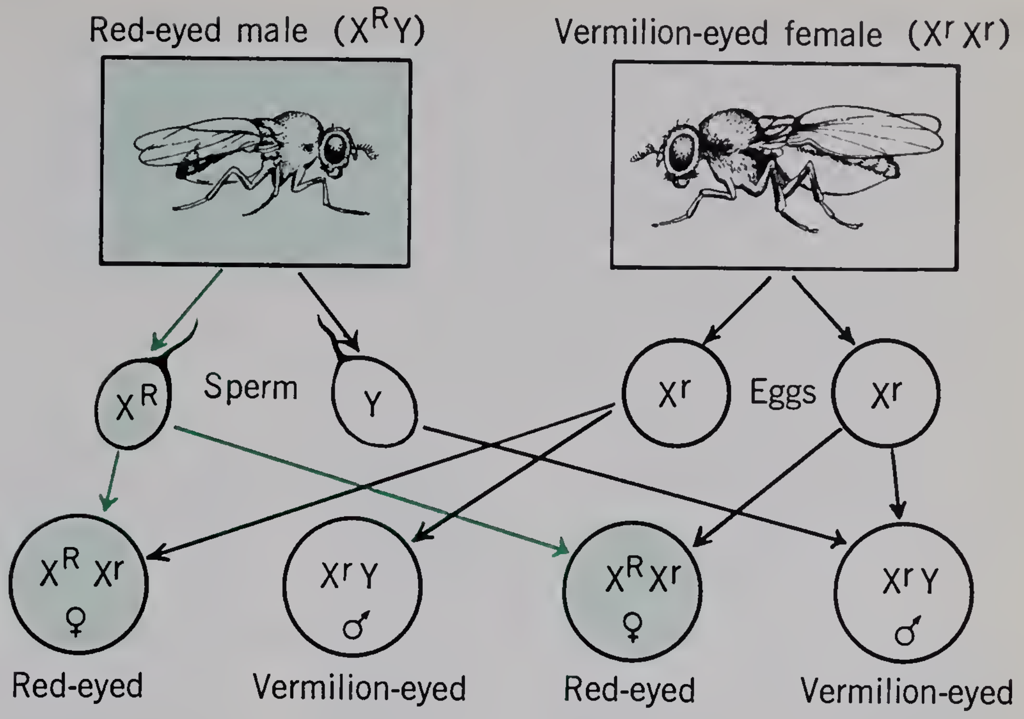
be males with a single gene for red eyes. All members of this generation would be red-eyed, however, because of dominance of the red eye gene.

In mating two flies of this generation, the offspring shown in the grid at the right would occur in the F_2 generation. Half of the eggs produced by a female of this generation would contain X^R and half would contain X^r. Half of the sperm would contain X^R and half Y. Thus, you can see that some of the offspring would be X^RX^R and others would be X^RX^r. All of these flies would be red-eyed females. On the other hand some of the males produced would be X^RY, with red eyes, while others would be X^rY, with white eyes. Actually, the law of averages would probably result in about a quarter of the offspring being of each type. This would result in an eye color ratio of three-quarters red-eyed and one-quarter white-eyed. Furthermore, all of the white-eyed offspring would be males, as Morgan determined.

Will a white-eyed female appear if mating is continued for another generation? This could result if a heterozygous red-eyed female, X^RX^r, were mated with a white-eyed male, X^rY.


White-eyed male (Xr Y)
Red-eyed female (XRXR)
P1
Xr
Sperm
Y
XR
Eggs
XR
XRXr ♀
Red-eyed
XRY ♂
Red-eyed
XRXr ♀
Red-eyed
XRY ♂
Red-eyed
Red-eyed male (XRY)
Red-eyed female (XRXr)
F1
XR
Sperm
Y
XR
Eggs
Xr
F2
XRXR ♀
Red-eyed
XRY ♂
Red-eyed
XRXr ♀
Red-eyed
XrY ♂
White-eyed

10-7 Sex linkage in *Drosophila.*



10-8 Normal cross in *Drosophila* between a red-eyed male and a vermilion-eyed female.

RESULTS OF CROSSING F_1 HYBRIDS RED–EYED MALE AND RED–EYED FEMALE

Female SEX CHROMOSOMES Male	X^R	X^r
X^R	X^RX^R	X^RX^r
Y	X^RY	X^rY

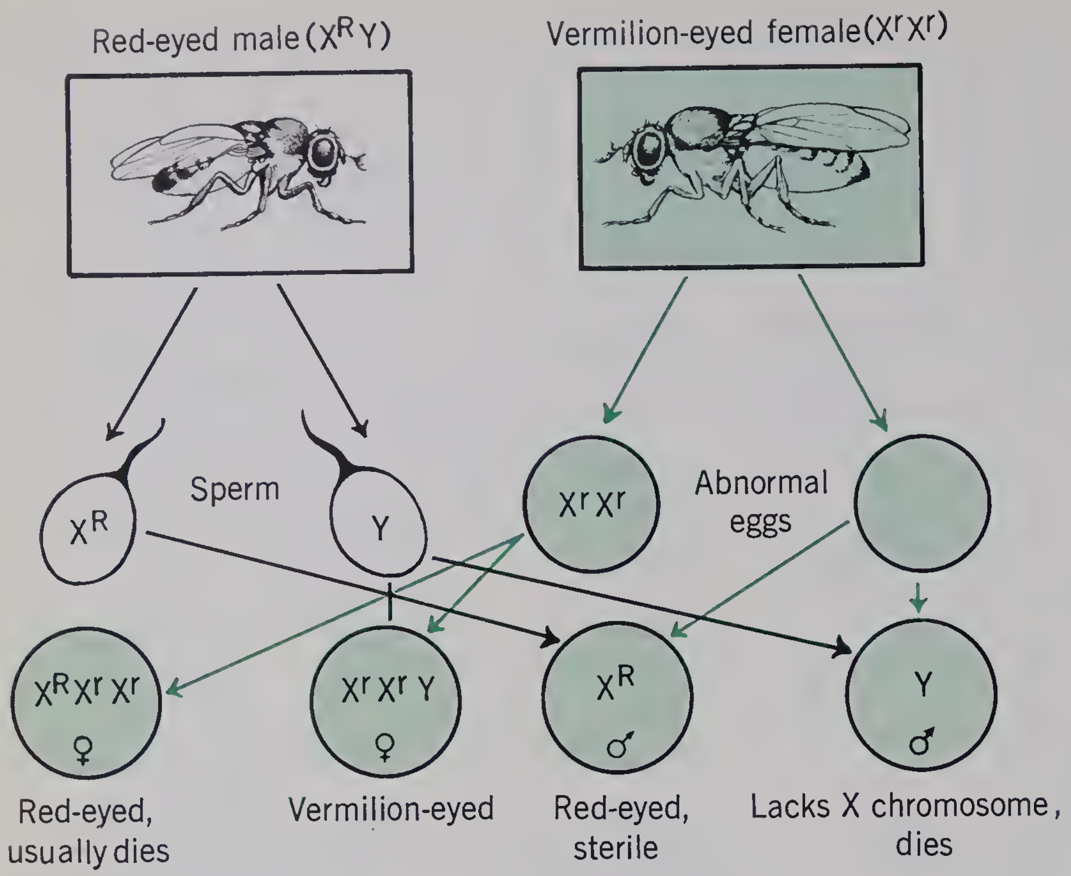
The discovery of ***sex linkage*** in *Drosophila* by Morgan and his associates introduced a new and important principle in genetics. Sex-linked traits are by no means limited to *Drosophila*. Did you know that color blindness occurs as much as 10 times more frequently in men than in women and that a similar ratio is found among victims of hemophilia, or "bleeder's disease"? Does this ratio of occurrence give you a clue? We shall reserve the discussion of the inheritance of these conditions for Chapter 11.

Other characteristics associated with sex are not sex-linked. For example, baldness is far more common in men than in women. Yet it is not a sex-linked trait. Conditions such as this will also be discussed in Chapter 11.

Nondisjunction – abnormal segregation of sex chromosomes. About ten years after Morgan discovered sex-linked traits in *Drosophila*, C. B. Bridges, one of his former graduate students, made another startling discovery. Bridges was working with sex-linked genes that determine eye color in *Drosophila* much as he had in the earlier studies in which he assisted Morgan. In these genes, however, the alleles were red eyes and vermilion eyes. Red eyes in *Drosophila* are dark red, while vermilion eyes are much brighter red. The gene for normal red eyes is dominant over that for vermilion. These genes normally behave as other sex-linked traits. When a vermilion-eyed female is mated with a red-eyed male, half the offspring are red-eyed females and half are vermilion-eyed males, as below and in Fig. 10–8.

RESULTS OF CROSSING VERMILION–EYED FEMALE AND RED–EYED MALE

Female SEX CHROMOSOMES Male	X^r	X^r
X^R	X^RX^r	X^RX^r
Y	X^rY	X^rY



10-9 Nondisjunction in *Drosophila.*

In about one individual in 2,000, however, a striking thing occurred. A vermilion-eyed female mated with a red-eyed male produced a vermilion-eyed female. If you examine the results of such a cross as shown you will discover that this is impossible under normal conditions. In the grid and in Fig. 10–8 the dominant gene for red eye color is represented as *R* and the recessive gene for vermilion eye color as *r*. The male fly with red eyes is represented as X^RY, while the vermilion-eyed female is X^rX^r. Females in the F_1 generation must receive an X^R chromosome from the male parent and an X^r chromosome from the female parent. How, then, could a vermilion-eyed female result? This would require two X^r chromosomes, both of which are in the female parent. Yet it did happen and threatened to upset the whole theory of sex-linked traits. To Bridges, this one-in-two-thousand female fly with vermilion eyes had great genetic significance. Surely, it could be accounted for in terms of sex chromosomes and sex-linked traits. The answer was to be found in the cells of the fly. Bridges examined cells from the fly's body and found a remarkable condition. This vermilion-eyed female had two X chromosomes and a Y chromosome. We would represent it genetically as X^rX^rY. The extra X chromosome produced a female, even in the presence of the Y chromosome. The two recessive genes located on these X chromosomes produced vermilion eyes — an impossibility in this mating under normal conditions.

Figure 10–9 shows how abnormal chromosome segregation occurred to produce this unusual situation. We refer to the phenomenon as ***nondisjunction.*** The red-eyed male parent produced normal sperm, half containing the X^R chromosome and half containing the Y chromosome. However, segregation of the X^rX^r of the female fly did not occur when eggs were formed. Thus, half of the eggs contained X^rX^r chromosomes, as in the somatic cells, while half contained *no sex chromosomes.* Notice in Fig. 10–9 that four kinds of offspring may be produced by various egg and sperm combinations:

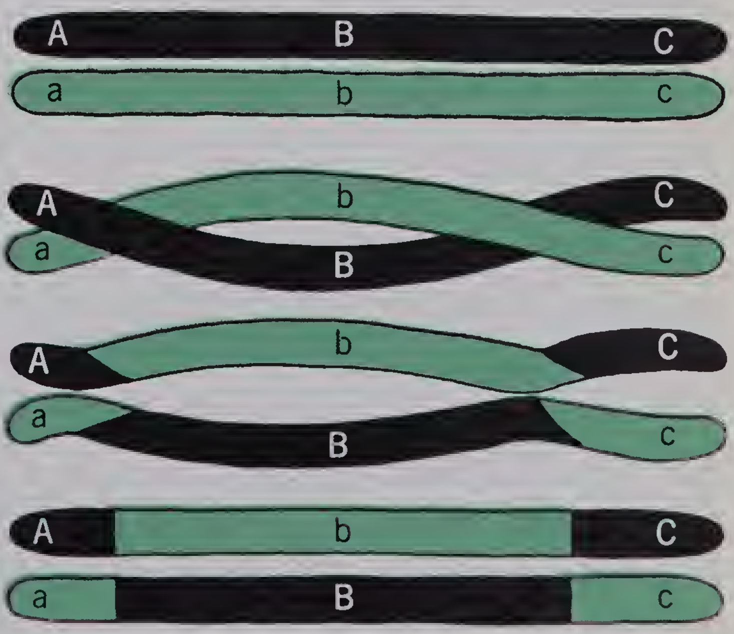
¼ red-eyed females ($X^RX^rX^r$), which usually die
¼ vermilion-eyed females (X^rX^rY)
¼ red-eyed males (X^R), which lack a chromosome and are sterile
¼ flies (Y), with no X chromosomes and therefore no eye-color genes, which always die.

In discovering nondisjunction, Bridges, far from disproving the chromosome theory of heredity, substantiated it further. His work left no doubt that genes are located on chromosomes and that the genes for eye color in *Drosophila* are on the X chromosomes.

Nondisjunction may occur in various autosomal chromosomes as well as in sex chromosomes. Recent studies of this phenomenon in human beings has explained the heredity of various tragic conditions such as Mongolian idiocy. We shall discuss this condition in Chapter 11.

Gene linkage and crossing over. Keep in mind that it is chromosomes and not individual genes that segregate during meiosis. Furthermore, a single chromosome contains a large number of genes joined together in a linear arrangement. We refer to this condition as ***gene linkage.*** If a chromosome has 50 genes linked together, its mate will have the alleles, or the 50 corresponding genes. Thus an organism can have no more pairs of genes sorting out independently than it has pairs of chromosomes.

However, this linkage is not perfect. Segments of chromosomes, bearing many genes, may separate and exchange with a corresponding segment of the other member of a chromosome pair. We refer to this phenomenon as ***crossing over.*** When do you think a homologous pair of chromosomes would be most likely to exchange segments? When are they in closest contact? Do you remember in meiosis when the genes have replicated and each chromosome forms two chromatids? The joined chromatids of a homologous pair come together and form a tetrad, or group of four. It is here that segments of two chromatids (one of each homologue) may exchange segments containing varying numbers of genes. For example, let us represent three of the many genes on a chromatid as *A*, *B*, and *C*. Corresponding genes on a chromatid of the other homologue are *a*, *b*, and *c*. Now, we will assume that a segment of one chromatid separates between genes *A* and *B*. A similar separation occurs between genes *a* and *b* of another chromatid. These two chromatids exchange segments and produce a new gene linkage on two of the four chromatids in the tetrad. These new linkages are now *a*, *B*, and *C* and *A*, *b*, and *c*. Following separation of the chromatids in meiosis, eggs or sperm will receive these new gene combinations not present in either parent. We have described a single crossover. Double and even triple crossovers are known to occur.



10-10 Crossing over. Note the final result, which is a new grouping of genes on the chromosomes.

The genes shown on the chromosome diagrams in Fig. 10–10 are widely separated. Biologists have reasoned that the greater the distance between two genes on a chromosome, the more likely a separation will occur between them. The rate at which these separations occur in specific chromosomes has been used as an index in determining the distance between two genes. This is one of the ways in which geneticists have been able to construct ***chromosome maps*** locating the genes in relation to each other. Such chromosome mapping has been done for both *Drosophila* and corn. Similar methods are being used to locate specific genes on human chromosomes.

What is a gene? Our discussion so far has concerned chromosomes and the genetic traits that genes produce. But what is a gene and how does it operate? Why does one gene produce a short pea plant while another produces a tall plant? To answer these questions, we must return to the DNA molecule. Remember that chromosomes contain DNA, and that DNA is able to replicate itself every time mitosis occurs and two new cells result from one. Remember also that the DNA in every cell of the body bears the ***genetic code***, which determines the traits of an organism, and that by means of messenger RNA, it transmits this coded information and thus controls all cellular activities. Thus it is evident that a gene must be defined in terms of the DNA molecule. Let us review the structure of that molecule to establish this relationship.

We noted in Chapter 3 that the DNA molecule is in the form of a twisted ladder, or double helix. The side pieces are composed of alternating phosphate and deoxyribose sugar units. The steps of the ladder are formed by pairs of bases. Recall that there are four different bases — adenine, guanine, thymine, and cytosine — and that these bases may occur in any sequence as long as they are properly paired. Now, since the sequence of bases is the only variable part of the DNA molecule, it is logical to conclude that in this sequence lies the code that is able to control the numerous different traits of an organism. This is indeed the case.

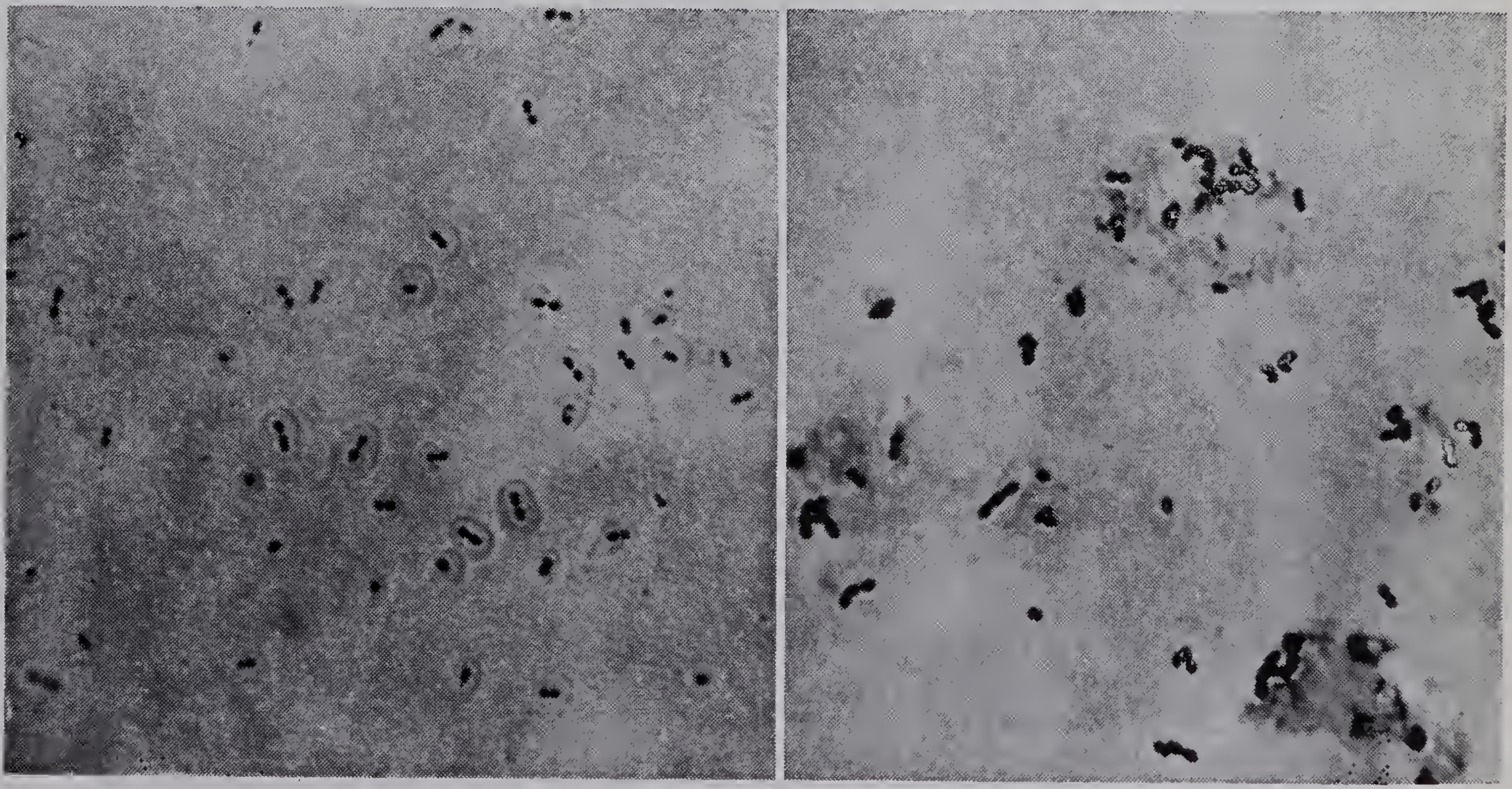
In Chapter 6 we described the separation of the two strands of the DNA molecule, the formation of RNA from a single strand of DNA, the movement of this RNA to a ribosome where it becomes a template, and the coding of a protein molecule by the arrangement of bases in the template. Thus, in studying protein synthesis, we have already pinpointed the genetic code. The coded arrangement of bases ultimately determines what proteins will be produced. Since most proteins are enzymes, and enzymes direct all cellular activities, we have arrived at a logical explanation for genetic control of the organism.

In Chapter 6 we referred to the current evidence that a triplet of bases acts as a code for a single amino acid. Thus the synthesis of a protein that contains 100 amino acids would require a portion of a DNA molecule with 100 base triplets, or 300 bases. Actually no one has yet worked out the complete coding sequence of bases for a single protein. Also, there seem to be triplets along the sequence that do not act as code "words," but might be called "nonsense syllables." They may be "punctuation marks" indicating the end of a protein or part of a protein, although this is not established.

Although we have described the genetic code, we have not yet defined a gene. Actually biologists are in some disagreement as to the definition of a gene. Chromosomes contain strands of DNA and other chromatin materials. The DNA is spiraled around a protein backbone. The nature of this binding seems to determine which part of the DNA molecule is active genetically. The ends of the molecule are not active. However, since the strands may contain hundreds of base pairs, many other parts of the molecule are active genetically. In general a gene may be defined as that portion of a DNA molecule that is genetically active and produces a trait — that is, it is a unit of hereditary information. Biologists are not agreed as to whether this unit should be defined as that which codes a single protein, more than a single protein, or only a portion of it. At any rate, it is becoming increasingly clear that the triplets of nitrogen-containing bases code amino acids. Also, it logically follows that each chromosome pair in the cells of a given organism contains different coding sequences, making possible the numerous genetic traits.

Transformation in pneumococcus — proof of DNA. Perhaps you have wondered how biologists have been able to prove that DNA is the genetic material. One of the most convincing proofs has been found in studies of pneumococcus, the bacterium that causes one kind of pneumonia. It is interesting that these studies began nearly 40 years ago with the work of an investigator who had never heard of DNA.

In 1928, Frederick Griffith, a British bacteriologist, was working with two strains of pneumococcus. The cells of the two strains were similar — tiny spheres usually joined in pairs or short filaments. However, there was a sharp distinction between the two strains. One formed a slimy capsule that surrounded the cells. The other did not. Griffith found that the noncapsulated organisms *did not* cause pneumonia.



10-11 The left-hand photograph shows the capsulated, infectious strain of *Diplococcus pneumoniae,* commonly called pneumococcus. The right-hand photograph shows the noncapsulated, noninfectious strain. (Robert Austrian and *Journal of Experimental Medicine*)

Apparently the cells were destroyed by white corpuscles when they were injected into a mouse or other test animal. However, mice that received injections of the capsule-forming strain were dead or dying of pneumonia within a short time. Apparently the capsule prevented white corpuscles from destroying cells of this strain.

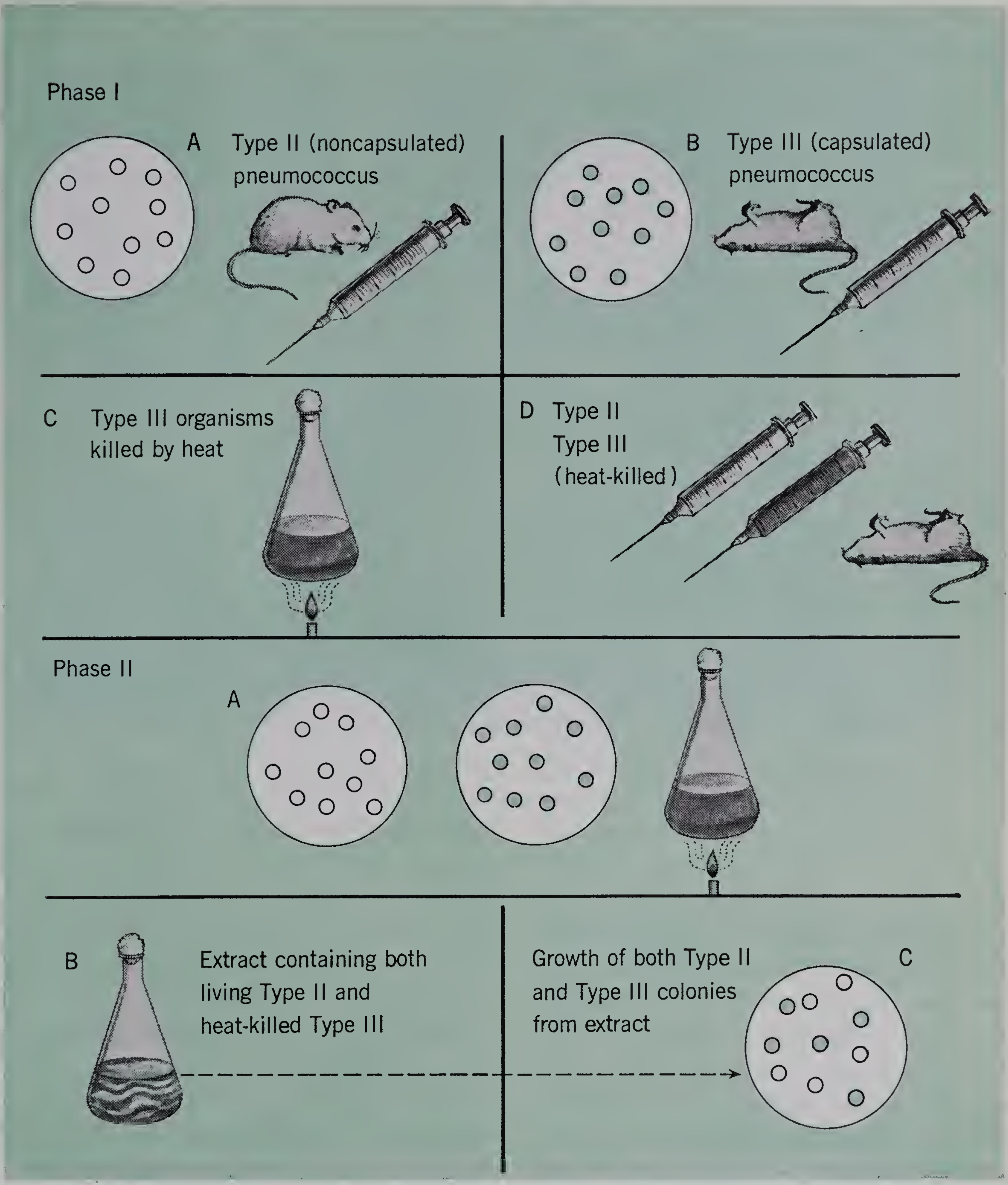
In one phase of his investigation, Griffith inoculated mice with the two strains of pneumococcus. In one injection he used living noncapsulated organisms. In the other he used capsulated organisms that had been killed with heat. Much to his surprise the mice soon died of pneumonia. When he examined the blood of these mice, he found pneumonia organisms *with capsules!* None of the capsulated organisms he had injected were living. Yet here were capsulated bacteria which, when placed in cultures, continued to grow and were therefore alive. Apparently the living noncapsulated cells had been transformed into a capsule-producing strain (Fig. 10–12, Phase I).

About 15 years later Oswald T. Avery and his associates, C. M. MacLeod and M. McCarthy, began a search for an explanation of Griffith's results at the Rockefeller Institute for Medical Research in New York City. They grew both noncapsulated (Type II) and capsulated (Type III) pneumonia organisms in laboratory cultures. The capsulated organisms formed slimy colonies on the surface of the culture medium that were easily distinguished from colonies of the Type II organisms. Each strain continued to produce its own characteristic cells generation after generation. They next prepared an extract of heat-killed Type III capsulated cells and mixed it with living Type II noncapsulated cells. When this extract was cultured in a sterile medium, a few Type III colonies appeared. These newly transformed capsulated cells were then isolated, cultured, and furthermore, these formerly noninfectious Type II cells now caused pneumonia when injected into mice. Some factor in the extract made from dead capsulated organisms had entered these cells and produced a genetic change. Avery and his associates were able to isolate and purify this transforming substance. At first it was thought to be a protein. However, it proved to be a nucleic acid or more specifically, DNA.

The discovery of the phenomenon of ***transformation*** in pneumococcus is of great genetic importance for at least two reasons. It proves that the gene is DNA. Furthermore, it demonstrates that genes can be transferred from one organism to another and continue to express their genetic qualities.

Gene action. Having established that genes determine hereditary traits and that they are in fact portions of DNA molecules, perhaps we should clarify the way genes act in producing traits. Remember that DNA acts through messenger RNA, which in turn encodes amino acids to synthesize proteins. What kinds of proteins? Most proteins are enzymes, which determine the chemical activity of the cell. Thus, RNA serves as the messenger in gene action, but enzymes are the active agents. You inherited a specific set of genes, which are present in pairs on your 46 chromosomes. As a result of the action of these many thousands of genes, you also have many thousands of enzymes controlling the chemical activities of your cells.

But let us examine this situation more closely. Every cell in your body normally contains all of your genes.


Phase I
A Type II (noncapsulated) pneumococcus
B Type III (capsulated) pneumococcus
C Type III organisms killed by heat
D Type II
Type III
(heat-killed)
Phase II
A
B
Extract containing both living Type II and heat-killed Type III
Growth of both Type II and Type III colonies from extract
C

10-12 The discovery of transformation in pneumococcus. Phase I—A. Griffith found that Type II (noncapsulated) pneumococcus did not cause pneumonia when injected into mice. B. When Type III (capsulated) pneumococcus was injected into mice, they contracted pneumonia and died. C. Type III organisms were killed by heat. D. When both living Type II organisms and heat-killed Type III organisms were injected, the mice died. Apparently some of the Type II had been transformed into Type III. Phase II — A. Type II and Type III pneumococcus were again cultured, and the Type III was heat-killed. B. An extract containing both living Type II and heat-killed Type III was prepared. C. When this extract was cultured on a sterile medium, some Type III colonies appeared. It was later determined that DNA from the heat-killed Type III had entered some of the noncapsulated pneumococcus cells and transformed them into capsulated cells.

This genetic makeup was established at the beginning of your life when an egg and a sperm combined their haploid chromosome numbers to produce a diploid zygote — your first somatic cell. From that moment on, every gene has replicated prior to a mitotic cell division. Thus every cell in your body contains your complete genetic code. If you have blue eyes, every cell contains genes for blue eyes. Yet only in the cells of the iris of your eyes is this trait expressed. Here the gene for eye color produces enzymes which in turn regulate pigmentation of the iris. The cells of the iris also contain genes that determine the color and texture of your hair. But these genes act only on the cells of hair roots.

Could it be, then, that genes act only in a particular cell environment? They may do so because of differences in the chemical composition of the cytoplasm of various cells. Undoubtedly, many other unknown factors are involved. But we may be sure that genes and cells function in a close relationship in determining gene action. Blue-eyed people never have blue skin, and genes that determine blood type never express hair color or the shape of an ear!

Mutations — errors in the genetic code. Normally genes replicate and chromosomes segregate during meiosis with remarkable accuracy. This may occur millions of times without an error. Variations occur in offspring as new gene combinations are established in sexual reproduction. But the individual genes remain unchanged.

From time to time, however, an organism may appear with a characteristic totally unlike any of those of either parent. This new characteristic is transmitted to offspring. Thus we know that it represents a sudden genetic change rather than an environmental influence. We refer to such a change as a *mutation* and to the organism possessing it as a *mutant.* Any change in the base coding of a DNA molecule would alter or destroy the trait associated with the gene. This produces a *gene mutation,* also referred to as a *point mutation.* While less common than gene mutations, other mutations may occur as *chromosomal aberrations,* or *chromosome mutations.* These may be the result of nondisjunction during segregation in meiosis, loss of an entire chromosome or piece of a chromosome, or possibly the recombination of chromosome segments by crossing over.

If a mutation occurs in a body cell of a plant or animal, the variation appears in all of the tissue that descends from the original mutant cell. This is known as a *somatic mutation.* It is not transmitted to offspring since reproductive cells are not involved. Somatic mutations may be preserved in plants, however, if the variation is desirable, by vegetative propagation. Somatic mutations have been the source of new plant varieties we shall discuss in Chapter 12. If a mutation occurs in a reproductive cell, it may be transmitted to offspring. Such *germ mutations* are of great genetic importance.

The nature of gene mutations. Minor mutations may occur from time to time with little or no visible effect on the organism. These are the most common of all mutations. However, a major mutation results in a drastic change in a characteristic. Minor mutations may be either beneficial or harmful. Major mutations are nearly always harmful. Many are *lethal* and result in death of the organism. Many lethal characteristics have been found in cattle. Among these are the parrot-beak calf, with abnormal

10-13 Lethal traits such as albinism in corn are due to gene mutations. These seedlings will live only as long as stored food in the endosperm is available to them. (A. M. Winchester)

jaw structure; short-spine calf with shortened and fused vertebrae; and an amputated calf lacking both lower jaws and legs. Mutation of a gene that controls chlorophyll production in a plant would be a lethal condition since a plant that lacks chlorophyll cannot carry on photosynthesis.

Mutations occur in all levels of life. They are known to occur in viruses and are frequent among bacteria. They have been found in all plants and animals that have been studied genetically. Human beings are also subject to mutations. We shall discuss some of these in Chapter 11.

A mutant gene is nearly always recessive to a normal allele. For this reason the mutation does not appear in a heterozygous individual. The gene is nevertheless passed to offspring and, paired with another mutant gene from a heterozygous parent, would produce the characteristic.

The rate at which different mutations occur varies considerably, as some genes seem to be more chemically stable than others. Some mutate as often as once in 2,000 cell divisions, while others mutate only once in millions of cell divisions. Sometimes genes mutate several times in rapid succession. They often mutate and then mutate again back to the original form. Of course, the rate at which many genes mutate is difficult to determine because the mutation has no apparent effect on the organism.

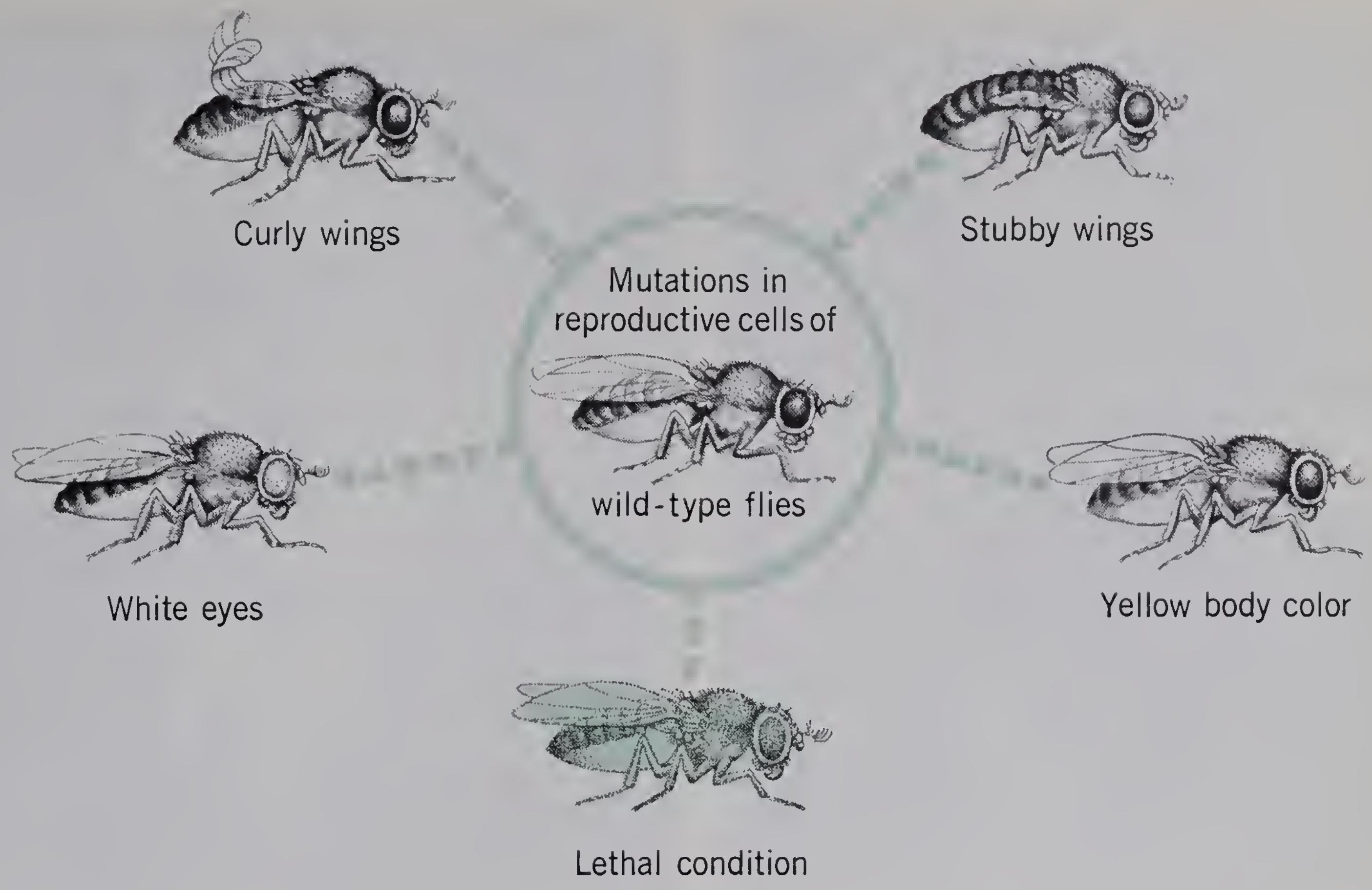
Causes of mutations. One of the most frequent causes of mutations is exposure to high-energy radiation. Cosmic rays from outer space and radiation from radioactive elements may cause natural mutations. They may also be produced experimentally by exposure to X rays, gamma rays, beta particles, and ultraviolet light. Biologists have used artificial sources of radiation to increase both the number and the rate of mutations in organisms under experimental conditions. Temperature increase has also been used to increase the rate at which mutations occur. Certain chemicals have also been used to produce mutations. Among these are formaldehyde, nitrous acid, peroxide, and mustard gas.

Radiation as a cause of mutations. The first proof that radiation causes mutations came from research conducted by Hermann J. Muller in 1927. Muller was one of the graduate students who worked with Morgan and Bridges at Columbia University in the early studies of inheritance in *Drosophila.* While at the University of Texas, Muller conducted a series of experiments to establish that radiation can cause mutations and that their rate can be increased with artificial radiation. As in his earlier work, Muller used *Drosophila* in his investigations. His work, for which he received the Nobel prize in medicine and physiology in 1946, represents one of the most significant advances in genetics.

10-14 Dr. Hermann J. Muller first showed that radiations cause gene mutations and won the Nobel prize in 1946 for his outstanding contribution to genetics. (Indiana University)

Prior to Muller's work, geneticists had tried many methods of producing mutations artificially without success. They had experimented with temperature changes, variation in light conditions, different diets, and other factors on various animals, including *Drosophila.* One thing these other investigators probably overlooked that Muller considered was a condition under which a gene mutated. Consider that a pair of genes, normal for an organism and lying close to each other in corresponding positions on corresponding chromosomes, would be affected equally by chemical changes in the cell or an environmental condition such as temperature. Suddenly one gene of the pair mutates while the other remains unchanged. What could change one gene and not the other? The most likely cause of such a pinpoint effect would be high-energy radiation. It was to prove this idea that Muller began his series of experiments. Muller reasoned, further, that lethal mutations would be the most likely to result from radiation.

The following is a greatly simplified summary of the brilliant work Muller conducted. He selected a male *Drosophila* with known sex-linked traits and radiated it with a strong dose of X rays. This fly was mated with a



10-15 This drawing shows some of the various mutations that occur in the reproductive cells of wild-type *Drosophila.*

female with known sex-linked genes on the X chromosomes. The female was not radiated. In the F_1 generation, half of the flies were females, all containing a radiated X chromosome from the male and a normal X chromosome from the female parent. The other half were males, containing a normal X chromosome from the female and a radiated Y chromosome from the male parent. When two of these particular flies were crossed, four kinds of offspring should have been accounted for in the F_2 generation. This mating should have resulted in about one-fourth females with two normal X chromosomes, one-fourth females with one normal X chromosome and one radiated X chromosome, one-fourth males with a normal X chromosome and a radiated Y chromosome, and one-fourth males with both X and Y chromosomes radiated. However, this last group of flies did not appear. The radiated X chromosome bore a lethal gene that prevented them from developing. This did not occur in the females that contained a radiated X chromosome because of a dominant gene on the other X chromosome.

Since Muller's original work, he and other geneticists have produced many more mutations in *Drosophila* as well as in other organisms. Artificial radiation has been found to increase the rate at which mutations occur as much as 150 times above the normal frequency.

A common mold with great genetic significance. Much of the research in genetics today is being conducted with simple organisms, including molds and bacteria. Experimental results may be obtained quickly because of the short-life cycles of these organisms. Furthermore, metabolic processes may be studied readily, thus establishing evidence of gene action in cell biochemistry.

One such organism which has been the subject of extensive genetic studies

10-16 The common baker's mold *Neurospora* is one of the most widely used organisms in research concerning genetic mutations. (David R. Stadler)

in recent years is the common baker's red mold, *Neurospora crassa.* This common mold, a relative of the yeasts, may be found growing on bread and other food products. As the mold grows, it forms a mass of white threads which penetrate the medium. Within a short time, stalks arise above the medium. The tip of each stalk becomes a spore case in which eight salmon-pink spores are produced. Each spore may produce a new mold plant.

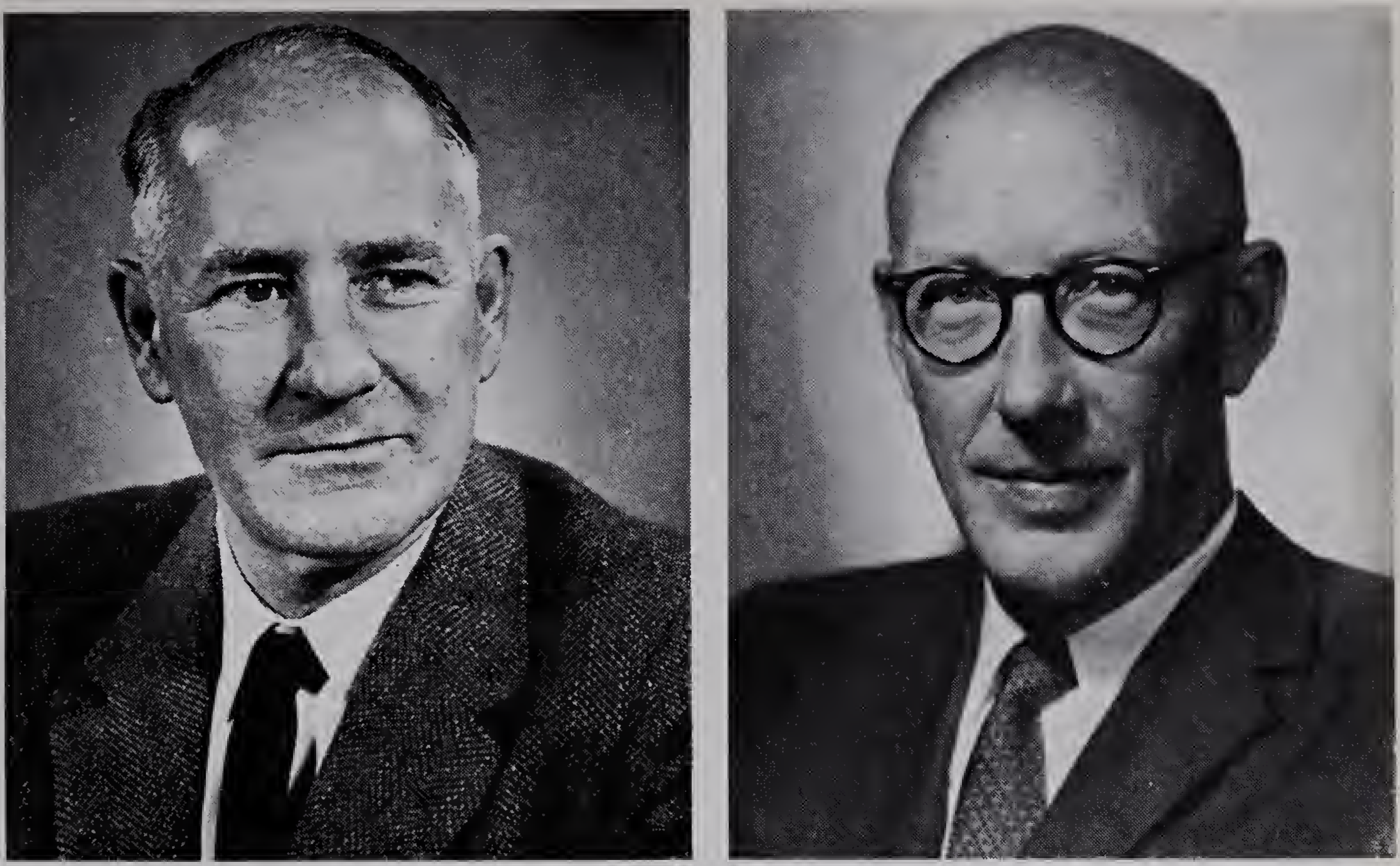
While we would consider *Neurospora* a primitive organism from the standpoint of evolution, it is far from simple in its biochemical capacity. The chemical abilities of this mold far surpass those of more highly evolved organisms, including most animals. *Neurospora* can be grown on a simple medium containing only salts, sugars, and biotin, which is a vitamin.

It is known now that *Neurospora* can synthesize amino acids and produce its own vitamins as well as proteins, and form carbohydrates, fats, nucleic acids, and other essential substances. However, all of these processes require specific enzymes. These, we know today, are related directly to DNA. The fact that many enzymes function in a series of metabolic processes has made *Neurospora* an ideal subject for the study of genetic mutations and the influence of genes on enzyme production.

Altered genes and interrupted metabolic process. *Neurospora* came into prominence in genetic studies when it was used by two investigators at Stanford University in important experiments in the 1940's. George W. Beadle and Edward L. Tatum produced several mutations in *Neurospora* by exposing the spores to X rays. After treatment the spores were placed in the simple medium normally used to culture the mold. Beadle and Tatum found that certain of the treated spores could not grow in the simple medium. Apparently a mutation had occurred that prevented these spores from synthesizing certain substances essential for growth. The question now was what substance or substances could no longer be synthesized and whether a single gene or several genes had mutated in causing that particular condition.

They next prepared a simple medium to which they added all vitamins and essential amino acids. The spores germinated and produced apparently normal mold plants in this medium. Spores produced by this mutant mold supplied the investigators with material to test the same mold in other nutrient solutions.

At this point in the investigation, Beadle and Tatum devised a method of determining which one of 20 amino acids the mutated *Neurospora* could no



10-17 Dr. George Beadle (left) and Dr. Edward L. Tatum (right) were responsible for producing mutations in *Neurospora* by exposing the spores to X rays. (Left: University of Chicago; right: Rockefeller Institute)

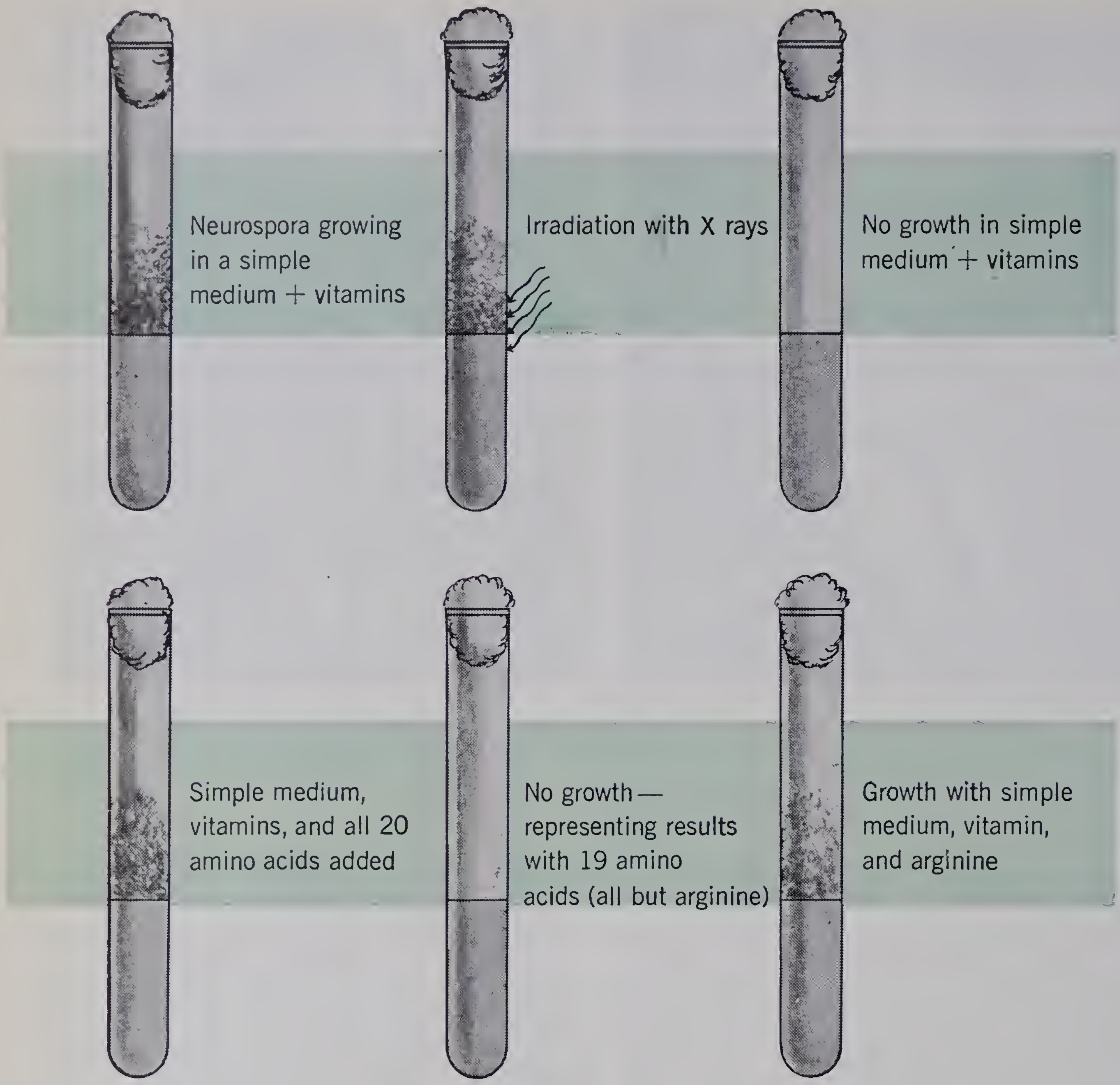
longer synthesize. They prepared 20 tube cultures, each containing the simple nutrient solution, vitamins, and a different amino acid. Each culture was inoculated with spores of the mutated mold. Growth occurred in only one of the 20 cultures. This was in the tube containing the amino acid *arginine*. This indicated that X rays had altered or destroyed the gene or genes controlling the synthesis of this essential amino acid.

Biochemists had established earlier that arginine is synthesized in a series of chemical steps. This chemical sequence begins with a prior substance from which *ornithine*, a nitrogen-containing organic molecule, is formed. In a second step, *citrulline* is produced from ornithine. *Arginine* is in turn synthesized from citrulline.

The next question concerned the relation of the damaged genes in the mutated *Neurospora* to this series of processes. Were all three steps normally controlled by a single gene, or was a different gene associated with each step in the process? Beadle and Tatum suggested that each step involved a different gene and that any or all of these genes might be involved in the mutation. We can diagram the chemical steps leading to arginine and the possible relation of genes to each as shown below.

If any one or all three of these genes had mutated, the mold could grow if arginine were added to the cul-

$$\begin{array}{c}\text{prior}\\\text{substance}\end{array} \xrightarrow{\text{gene A}} \text{ornithine} \xrightarrow{\text{gene B}} \text{citrulline} \xrightarrow{\text{gene C}} \text{arginine}$$


Neurospora growing in a simple medium + vitamins
Irradiation with X rays
No growth in simple medium + vitamins
Simple medium, vitamins, and all 20 amino acids added
No growth — representing results with 19 amino acids (all but arginine)
Growth with simple medium, vitamin, and arginine

10-18 This is the technique used by Beadle and Tatum to detect a nutritional mutant in *Neurospora* and to identify an amino acid which could not be synthesized.

ture. However, if only gene A had mutated, the mold could grow if ornithine, citrulline, or arginine were added. If gene B or both A and B mutated, their normal functions could be bypassed by adding citrulline or arginine. In the event of a mutation in gene C, arginine would have to be added, even if genes A and B were functioning normally. Beadle and Tatum tested these possibilities by adding the different compounds to the culture media of various mutants. They found that their reasoning had been correct that a different gene was in fact involved in each step.

The work of Beadle and Tatum with various mutated strains of *Neurospora* established the "one gene — one enzyme" hypothesis of gene action. Actually, it was an enzyme and not the gene itself that was necessary for each step in the series of reactions leading to arginine. However, a gene was necessary for the synthesis of each enzyme. Mutation destroyed the capability of a gene to produce an enzyme, thus block-ing the synthesis of arginine. For their brilliant work in investigating gene action, Beadle and Tatum were awarded a share of the Nobel prize in medicine and physiology in 1958.

Would it surprise you to learn that a similar series of chemical changes occurs in the cells of your liver? Here ornithine is converted to citrulline, which in turn is used in producing arginine. Arginine is converted to ornithine by reacting with $NH_3 + CO_2$. The urea also produced is excreted. This series of changes occurs in what biochemists refer to as the ornithine cycle.

IN CONCLUSION

As you read of the achievements of great biologists in searching for the materials of genetics you were, perhaps, aware of the narrowing of the search as more and more discoveries were made. The spotlight has narrowed from cells to nuclei to chromosomes to genes and, finally, to DNA and the bases that provide its genetic code.

The years ahead promise even more exciting discoveries because men like Sutton, Morgan, Bridges, Griffith, Muller, Beadle, and Tatum provided a firm foundation for genetics in the future.

BIOLOGICALLY SPEAKING

autosome
chromosome map
crossing over
gene linkage
genetic code
lethal mutation
mutant
mutation
nondisjunction
sex chromosome
sex linkage
transformation

QUESTIONS FOR REVIEW

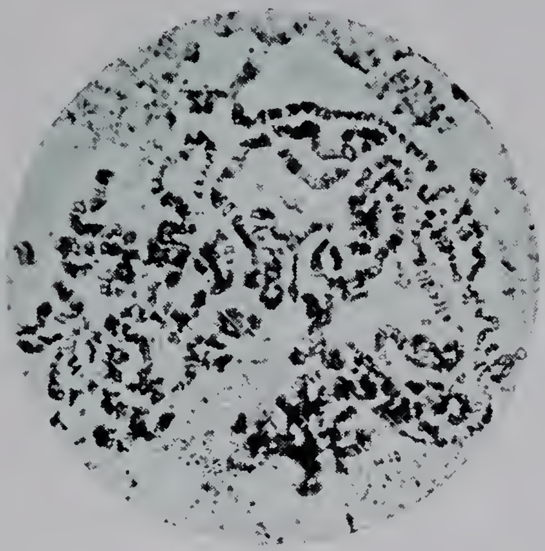
1. What logical conclusion led Weismann to propose that reduction division occurred in the formation of eggs and sperm?
2. List three parallels Sutton found between Mendel's hereditary factors and the behavior of chromosomes and genes?
3. Explain the principle of gene linkage that Sutton proposed.
4. Account for the fact that all seven of Mendel's contrasting traits sorted out independently.
5. Describe the chromosome makeup of *Drosophila.*
6. Explain how sex chromosomes function in determining the sex of an organism.
7. What is a sex-linked gene?
8. What characteristic did Morgan discover in the white-eyed *Drosophila* of an F_2 generation that led to his discovery of sex linkage?
9. Distinguish between sex chromosomes and autosomes.
10. Explain the mechanism of chromosomal nondisjunction.

11. How does crossing over alter gene linkage?
12. What is a chromosome map?
13. What observation in Griffith's work with pneumococcus led to the discovery of transformation?
14. Explain the relation of enzymes to gene action.
15. List several natural causes of mutations.
16. Distinguish between a somatic mutation and a germ mutation.
17. What energy source did Muller use to produce mutations in *Drosophila* by radiation?
18. Describe three steps in the synthesis of arginine by *Neurospora.*
19. In what ways did X ray-induced mutations alter the *Neurospora* studied by Beadle and Tatum?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the significance of the gene hypothesis proposed by Sutton.
2. Review the work of Morgan and his associates in the discovery of sex chromosomes and sex linkage.
3. Explain why nondisjunction is lethal in many offspring.
4. Discuss possible changes that might occur in a gene when it mutates in terms of what you have learned about the genetic code.
5. Discuss two important genetic principles illustrated in transformation.
6. Discuss the importance of Muller's selection of lethal sex-linked traits in his studies of mutation in *Drosophila.*
7. How did the work of Beadle and Tatum with *Neurospora* support the hypothesis of "one gene — one enzyme"?
8. Suppose that a mutant strain of *Neurospora* grew when arginine was added to it. Outline the procedure you would follow to determine which gene or genes had mutated.

CHAPTER 11



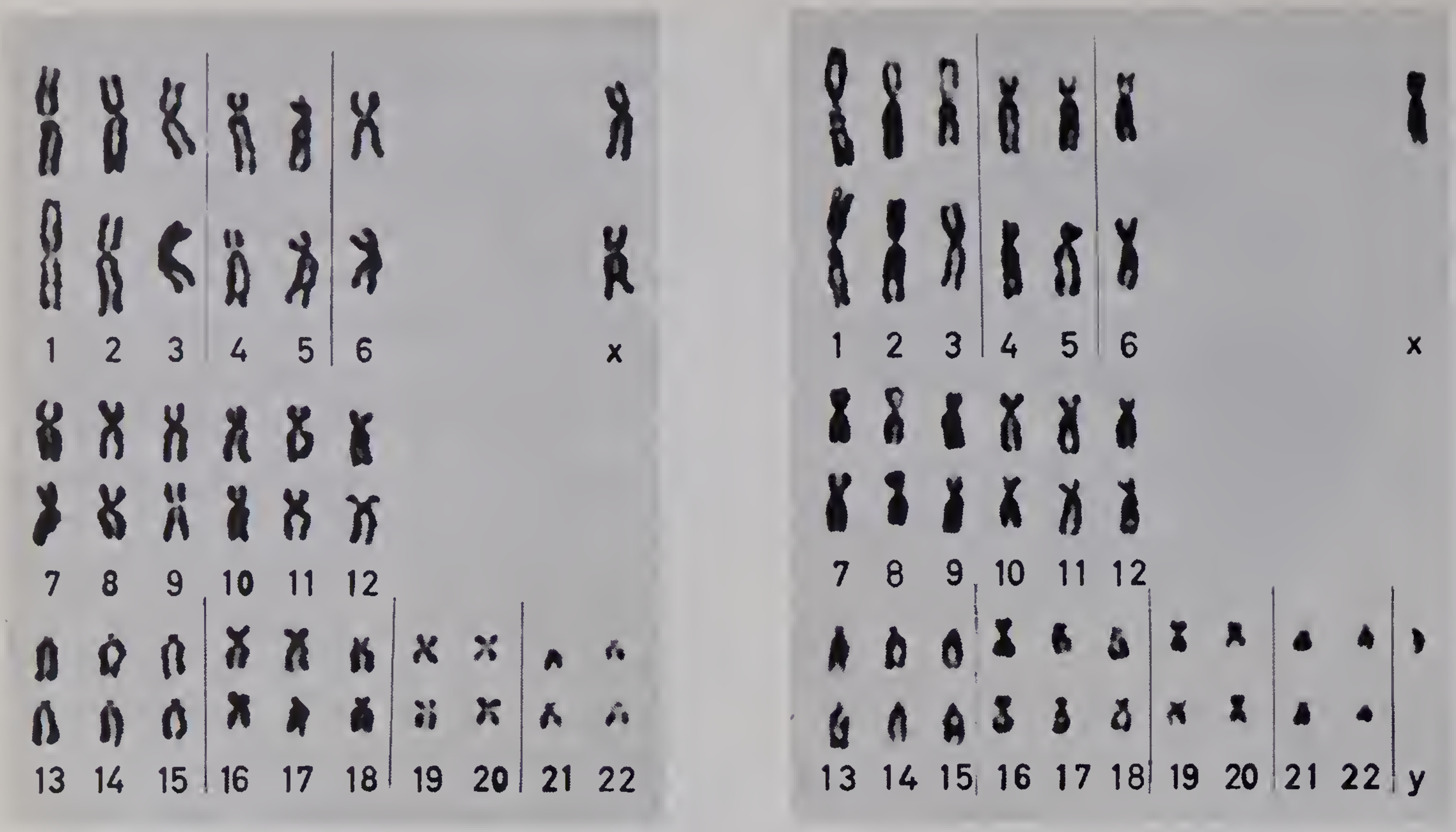
GENES IN HUMAN POPULATIONS

The nature of human heredity. Undoubtedly, as you have been reading the many accounts of genetic investigations in garden peas, guinea pigs, *Drosophila*, pneumococcus, *Neurospora*, and other organisms you have been thinking, do these same laws and principles apply to me? They do, of course, although we probably know more about inheritance in *Drosophila* than we do in humans. There are several reasons for this. One is the length of the human life span. An investigator can study many generations of *Drosophila* in a few months. Or, in bacteria, he can observe many generations in a week. But we do well to see six human generations in a lifetime. The number of individuals presents another problem in studying human genetics. A single mating in animals or a cross in plants may produce hundreds of offspring. When you compare this rate of reproduction with the limited size of human families, you can see that the family represents a very small sampling of genetic possibilities.

Perhaps the greatest problem in studying human heredity is separating the influence of heredity from that of the environment. Look at a human face. Perhaps a person has his father's ears and his mother's nose. We might account for his eye color and the color of his hair in terms of genes, but don't cares and worries or satisfaction and contentment leave their mark too? Similarly, genes may influence your height and the general build of your body, but so do your diet, your general health, and the activity of your glands. We know that glandular function is related to emotional states and these in turn reflect the conditions and events of your environment. Thus, another set of factors is introduced that complicates investigations in human genetics. This cannot be avoided since man is a thinking, reasoning, responsive organism.

Another complicating factor in human inheritance is the fact that most people come from mixed ancestry. Few, if any, human genetic traits are pure. Each time a marriage occurs, the genetic backgrounds of two entirely different families are combined in the offspring.

With all of these complications, however, geneticists have made extensive investigations of human genetics, especially in recent years. We know that the almost limitless number of human hereditary traits is produced by the action of an enormous number of genes on the 46 chromosomes in every body cell. When you consider the hundreds of genetic traits expressed in *Drosophila*,



11-1 Left: chromosomes of the human female; right: chromosomes of the human male. The numbers are those used by geneticists to label chromosomes for reference purposes. (Theodore T. Puck)

which has but four pairs of chromosomes, you can get some idea of the great variety of gene combinations we might have with 23 chromosome pairs. Is it any wonder, then, that among the hundreds of millions of people living in the world today there is no exact duplicate of you? That is, of course, unless you have an identical twin.

Population genetics. You will recall that Mendel established his laws of heredity by observing several generations of garden peas. No single generation could have supplied the data necessary to establish these principles. When geneticists started to apply Mendel's laws to human inheritance, the problem of limited numbers arose. Family characteristics could be traced from children to their parents and grandparents. Aunts, uncles, and other close relatives could be used. However, all of these individuals represented a small sampling. A family history might extend a study, but except for certain easily recognized traits, data concerning ancestors were usually vague and unreliable.

Has this thought ever occurred to you? You have two parents, four grandparents, eight great grandparents, sixteen great great grandparents, thirty-two great great great grandparents, and so on in numbers that double each generation. Each of these marriages united two different families. You may be surprised when you realize what a large segment of the population you may claim as distant relatives!

There is a better method of studying the frequency of genetic traits and predicting how often they will appear than attempting to trace them through families. Rather than extending the time to involve many generations, broaden the study to include a much larger sampling of a population at a given time. In other words, determine how frequently given genes appear in a population. From this information it is possible to predict the probability of appearance of any given genetic trait in offspring. ***Population genetics,*** as we call this study, is based on determinations of ***gene frequencies.***

Sampling a population. From time to time you read the results of an opinion poll in your newspaper. Based on a sampling of the population, the poll may predict the election of one candidate for political office and the defeat of another. It will even predict the margin of votes for the winning candidate. You may have been amazed at the accuracy of these polls. How can the results of the sampling of a relatively small percentage predict the opinions of the population of the entire nation? The accuracy of the prediction depends on the selection of a representative group of people in conducting the poll. The national population includes people of all ages, educational backgrounds, professions, trades, businesses, social backgrounds, races, cultural backgrounds, and economic levels. Our sampling, then, must include people from all of these groups and, of course, approximately equal numbers of men and women.

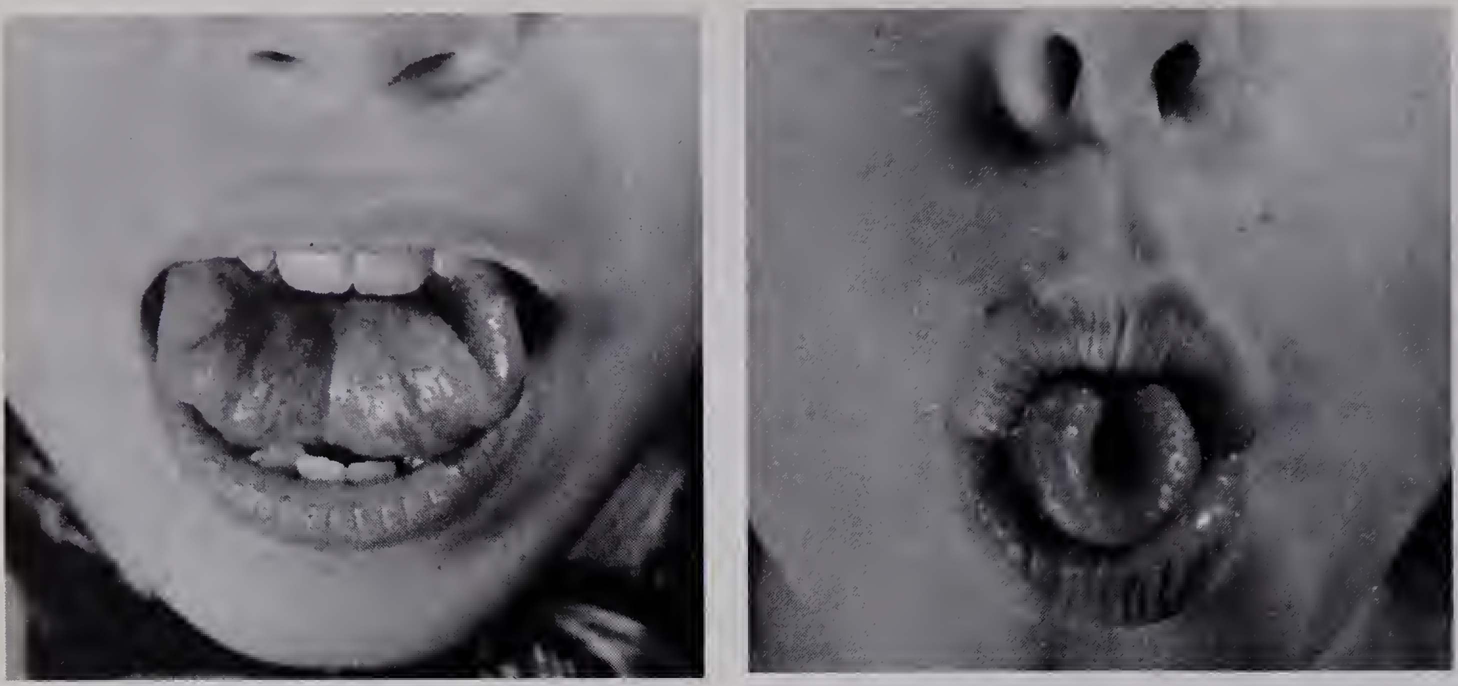
Now, let us apply this method of sampling to a genetic survey you might conduct in your class. The trait we will use will be the ability to taste *phenylthiocarbamide* (fenl-thy oh-*kar*-ba-myde) [PTC] on a strip of test paper. This substance is extremely bitter to some individuals referred to as "tasters," but has no flavor to a "nontaster." The ability to taste PTC is due to a dominant gene *T*. Thus a taster may be homozygous (*TT*) or heterozygous (*Tt*). A nontaster must be a homozygous recessive (*tt*). Now, let us assume that 24 members of your class ask 25 people to taste PTC papers. This would provide results from a total of 600 people. The poll should include people of various ages and both sexes to provide a representative sample. If possible, include people of different races and geographic and national backgrounds.

Let us assume that 430 people tested are tasters and 170 are nontasters. If we divide the number of tasters, 430, by the total number of people surveyed, 600, we find the result to be 0.716, or about 72 percent. The number of nontasters would then be about 28 percent of the people tested. This result would be near the national average, which has been determined to be 70 percent tasters and 30 percent nontasters.

Having determined the number and the percentage of tasters and nontasters in a sample of a population, it is a simple matter to establish the probable number of each in the total population. Let us assume that the population of your community is about 120,000, so that each person tested in your survey would represent 200 in the total population. Thus you would expect 86,000 people in the community to be tasters, while 34,000 would be nontasters.

Another interesting inherited trait which can be sampled in a population easily is tongue rolling. Some people can roll their tongues into a U-shape while others cannot. Since the gene for this characteristic is dominant, a tongue roller may be homozygous (*RR*) or heterozygous (*Rr*). Those who cannot roll their tongues are homozygous recessives (*rr*). Since tongue rolling involves a single pair of genes with dominance, you would expect a survey of a population for this trait to yield results similar to the PTC taster study.

The gene pool. The geneticist refers to all the genes present in a given popula-



11-2 The ability to roll the tongue is genetically determined. The characteristic is dominant, so that a tongue roller may be either homozygous or heterozygous for the trait. (A. M. Winchester)

tion as the ***gene pool.*** We might consider that any individual is a random sample of the genes present in his particular population. How frequently will a particular characteristic appear in a population? This will depend on the frequency in the population of the gene associated with that characteristic.

To return to our survey of tasters and nontasters of PTC, the fact that both of these characteristics appear in a population is evidence that both dominant genes (T) and recessive genes (t) are present. Furthermore, if you consider the national ratio of 70 percent tasters to 30 percent nontasters, you will see that this approximates a three fourths to one fourth ratio characteristic of a monohybrid cross with dominance. We might assume, then, that about one fourth of our population would be homozygous tasters (TT), one half heterozygous tasters (Tt), and one fourth homozygous nontasters (tt). This would indicate that the genes T and t are present in about equal numbers.

Might there be populations in some parts of the world where only the dominant gene is present in a population? All members of such a population would be tasters. Similarly, other populations might be entirely recessive for the trait.

As we examine various populations, we can see evidence of a high frequency of certain genes. The American Indian, for example, has characteristic dark, straight hair and facial features resembling the mongoloid peoples of northeastern Asia to whom anthropologists believe they are related. Following the migration of the Indians to North America perhaps 15,000 to 20,000 years ago, various culture areas were established from Alaska throughout North America and into Central America and South America. Certain gene pools were established in these culture areas and even in the tribes composing each one. The Eastern Woodland Indians had certain characteristics that distinguished them from Plains Indians or Southwest Farmers and Herders. The Eskimos of the Far North had characteristics that distinguished them

11-3 Identical twins such as these girls have the same genetic makeup, while fraternal twins are usually no more alike than ordinary brothers and sisters. (Strickler from Monkmeyer)

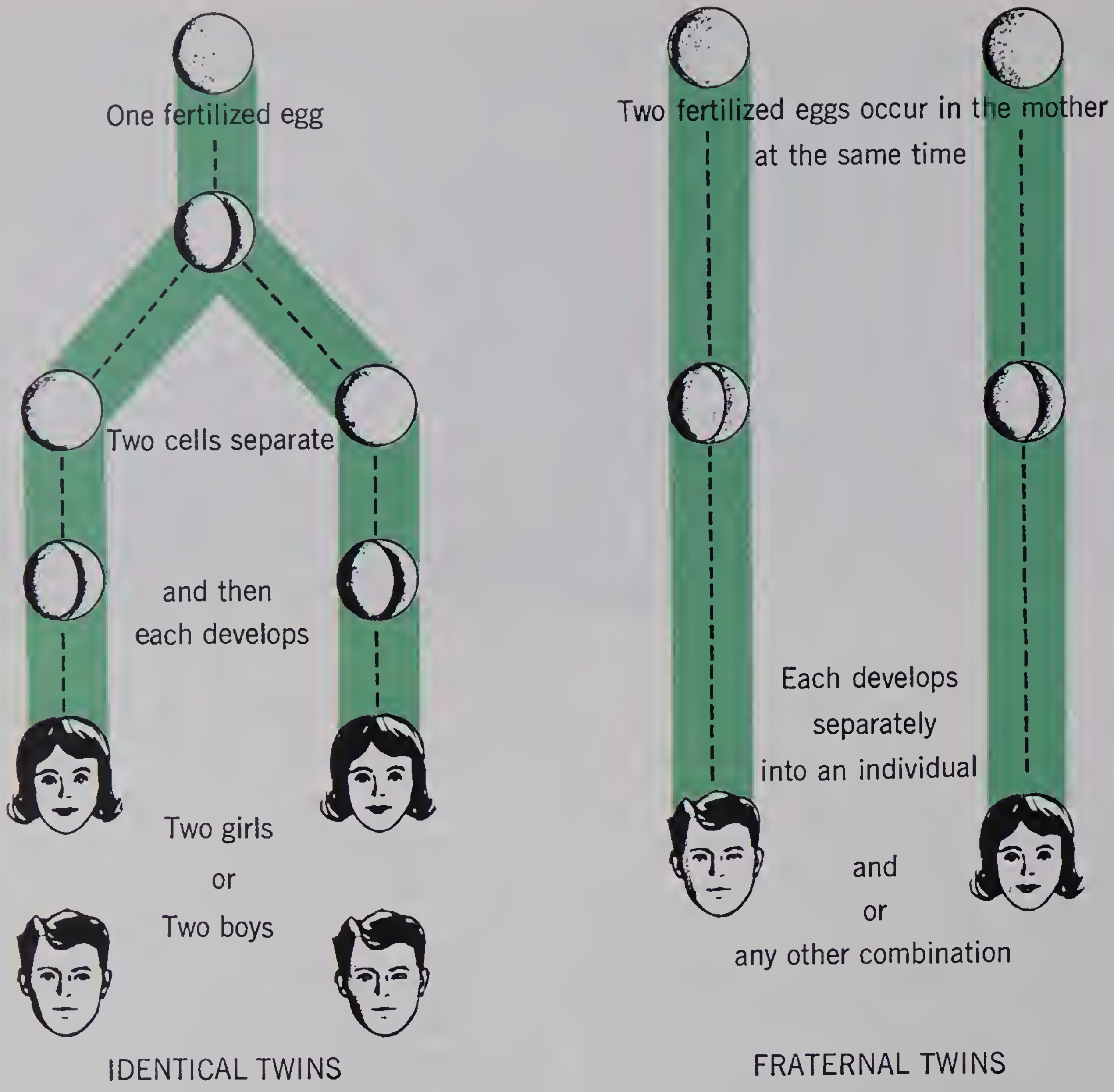
from the Northwest Fishermen along the Canadian Pacific Coastal region. Similarly, the African Pygmy of the Belgian Congo area is quite a contrast to the giant Watusi tribesman of the Lake Victoria region.

Although certain genetic traits may predominate in a population at a given time, gene pools change as populations shift. New gene combinations occur. These may appear as variations in skin color, hair color and texture, eye color, height and body build, and blood type. The more people that move from one geographical area to another, the more the gene pool changes.

Genetic studies of twins. Having considered the frequency of genes in human populations, let us now consider the expression of genes in individual members of a population. As we mentioned earlier, it is difficult to distinguish between genetic and environmental influence on certain traits in humans. In an effort to clarify the distinction, geneticists have made studies of twins. Twins are of two types. ***Fraternal twins,*** the more common type, are two entirely different individuals. Often they are brother and sister. They develop from separate eggs which are fertilized by different sperm. They are no more alike genetically and no more closely related than other brothers or sisters in a family. Most fraternal twins live in similar environments. Yet they may be totally different in physical characteristics, personality, emotional make-up, and mental ability. These variations are valuable in helping to determine which characteristics are hereditary and which are environmental.

Identical twins, on the other hand, are nearly the same person in duplicate. They started life as a single fertilized egg. But after the first division, the two cells separated and started growth over again (Fig. 11–4). Sometimes this happens several times, resulting in identical triplets, quadruplets, or quintuplets.

Having started life as the same cell, identical twins have identical genetic make-up. Consequently, the similarities in identical twins indicate, for the most part, characteristics controlled by genes. Identical twins show a marked likeness not only in appearance, but in temperament, abilities, likes and


One fertilized egg
Two cells separate
and then each develops
Two girls
or
Two boys
IDENTICAL TWINS
Two fertilized eggs occur in the mother at the same time
Each develops separately into an individual
and
or
any other combination
FRATERNAL TWINS

11-4 After having studied this diagram you will know that identical twins develop from a single egg, while fraternal twins develop from two fertilized eggs.

dislikes, and many other personality traits.

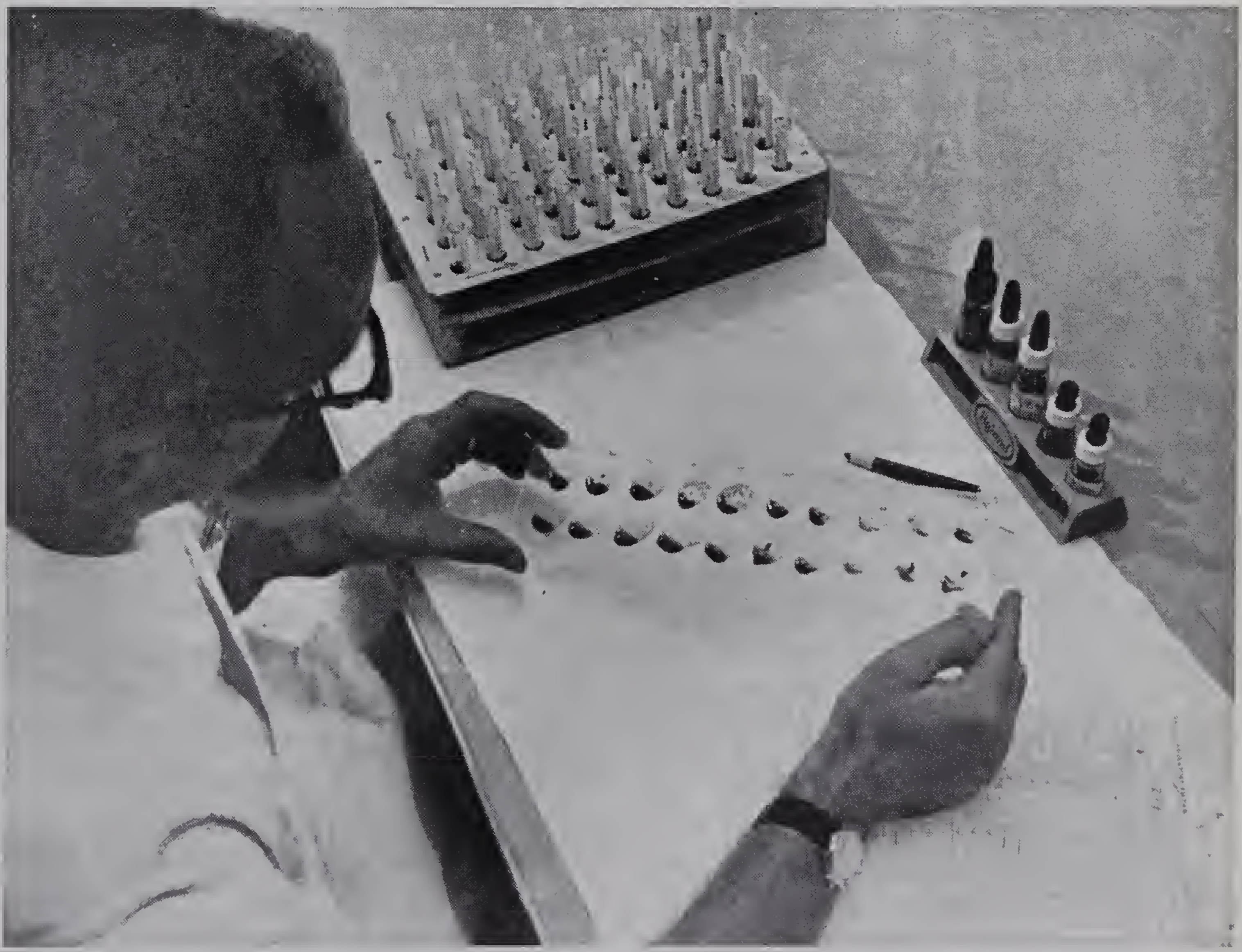
Several studies have been made of identical twins who were separated early in life and reared in different environments. In these instances, home and family life, education, day-to-day experiences, friendships, and other environmental influences leave their mark on the personality of each. But the two persons remain amazingly alike in appearance, basic personality traits, and capacity for learning. While they may vary somewhat in intelligence as determined by scores on tests, these differences indicate the influence of different environments rather than changes in basic capacity for learning. Unfortunately, the opportunities for studies of identical twins are very limited.

Genes in human populations – inheritance of blood type. Having discussed various methods used in the study of human genetics, we are now ready to consider a few hereditary traits in humans and the mechanisms involved in their inheritance. One such inherited trait is your blood type.

In 1900, while working in a medical laboratory of Vienna, Dr. Karl Landsteiner made an important discovery in a study of human blood. He found that the mixing of blood from certain people resulted in the clumping, or agglutination, of red corpuscles. In further investigations he found that the red corpuscles of various people differed in the presence of a protein substance on the corpuscle surface. This substance, which we know as an ***agglutinogen***, is one of two types. These were designated as type A and type B. Some corpuscles have one or the other, while some have both and still others have neither. Thus, we may designate all human blood as type A, B, AB, or O.

In Chapter 42, when we study the composition of blood, we shall deal with the reaction that occurs when certain different blood types are mixed. At present, we are concerned with the inheritance of blood type. Three genes are involved in this inheritance. We refer to them as ***multiple alleles***, since more than a single pair of genes is involved in determining the characteristic. However, even though three genes are associated with blood type, only two are present in any single individual. A gene we may designate as *A* produces type-A corpuscles, gene *B* results in type-B corpuscles, and gene *O* does not produce either agglutinogen on the corpuscles. Various combinations of pairs of these three genes results in the four human blood types as follows:

Genes *AA* or *AO* produce type-A corpuscles
Genes *BB* or *BO* produce type-B corpuscles
Genes *OO* produce type-O corpuscles (no agglutinogen)
Genes *AB* produce type-AB corpuscles (both agglutinogens)



11-5 Here a laboratory technician does A-B-O blood grouping on samples of blood collected in the Red Cross Blood Program. (American Red Cross)

In order to identify the three genes involved in corpuscle types as alleles, geneticists write the dominant as *I* and the recessive as *i*, and designate the agglutinogens they produce as I^A, I^B, and *i*. Using this system, then, type A may be homozygous I^AI^A or heterozygous I^Ai. Type B may be homozygous I^BI^B or heterozygous I^Bi. Type AB is always heterozygous I^AI^B, while type O is always homozygous *ii*. Determination of results in crossing individuals with different blood types is easily done with a grid such as you used for a monohybrid cross. A cross in which one parent is heterozygous type A (I^Ai) and the other is heterozygous type B (I^Bi) is shown below.

RESULTS OF CROSSING
I^Ai AND I^Bi

Female GENES Male	I^B	i
I^A	I^AI^B	I^Ai
i	I^Bi	ii

Notice that all four blood types may result in a cross such as this. The ratio of probabilities indicates that ¼ of the offspring should be type A, ¼ type B, ¼ type AB, and ¼ type O. This would be an unusual condition in a family, but it could happen.

In recent years anthropologists have conducted surveys of blood types among populations of the entire world. We have known the frequency with which these blood types appear in our own populations for many years. However, it is only in recent years that we have known how widely blood type frequencies differ in world populations. Such variations occur both among racial groups and in populations in different geographic regions. The following table shows certain of these variations.

Inheritance of the Rh factor. Many years after the discovery of the A–B–O blood types, Landsteiner and Wiener, an associate, discovered another protein substance in the red corpuscles of a Rhesus monkey. The protein was named the ***Rh factor*** for the monkey. Later it was found that 85 to 87 percent of the human population in the city of New York had corpuscles containing the Rh factor. They are designated as *Rh positive*. People who lack the factor are *Rh negative*. Serious complications result when Rh-positive blood is mixed with Rh-negative blood that has been sensitized against the factor, as you will learn in Chapter 42. At present we are concerned only with the inheritance of the factor.

At first it was thought that the Rh factor was a simple trait, present in some people and lacking in others. It was also thought to be controlled by a single pair of alleles in which the gene for the factor was dominant. However, we now know that there are four or more Rh factors believed to be determined by as many as four pairs of alleles. For this reason it is very difficult to diagram the inheritance of various Rh factors. You may be interested in knowing that, of the several Rh factors that have been discovered, only one, designated as the Rh^d factor, is of clinical importance.

Sex-linked genes in humans. Perhaps the best known sex-linked character in humans is *red-green color blindness*. While it rarely occurs in females, it appears in approximately 8 percent of the male population. People with this condition cannot easily distinguish red and green, both colors appearing as shades

BLOOD TYPE PERCENTAGES IN VARIOUS REGIONS OF THE WORLD

Blood Type	*A*	*B*	*AB*	*O*
U.S.A.-white	41.0%	10.0%	4.0%	45.0%
U.S.A.-Negro	26.0%	21.0%	3.7%	49.3%
Swedish	46.7%	10.3%	5.1%	37.9%
Japanese	38.4%	21.8%	8.6%	31.2%
Hawaiian	60.8%	2.2%	0.5%	36.5%
Chinese	25.0%	35.0%	10.0%	30.0%
Australian aborigine	44.7%	2.1%	0.0%	53.1%
North American Indian	7.7%	1.0%	0.0%	91.3%

of gray. The fact that it appears more frequently in males than in females would indicate that it is sex-linked. The genes associated with red-green color vision are located on the X chromosome. Furthermore, the gene for normal color vision is dominant. Thus, we may indicate various gene combinations as follows, using C for normal red-green color vision and *c* for color-blindness:

X^CX^C, a normal female, homozygous for color vision
X^CX^c, a carrier female, heterozygous but with normal vision
X^cX^c, a color-blind female, homozygous for color-blindness
X^CY, a normal male with a single gene for color vision
X^cY, a color-blind male with a single gene for color-blindness

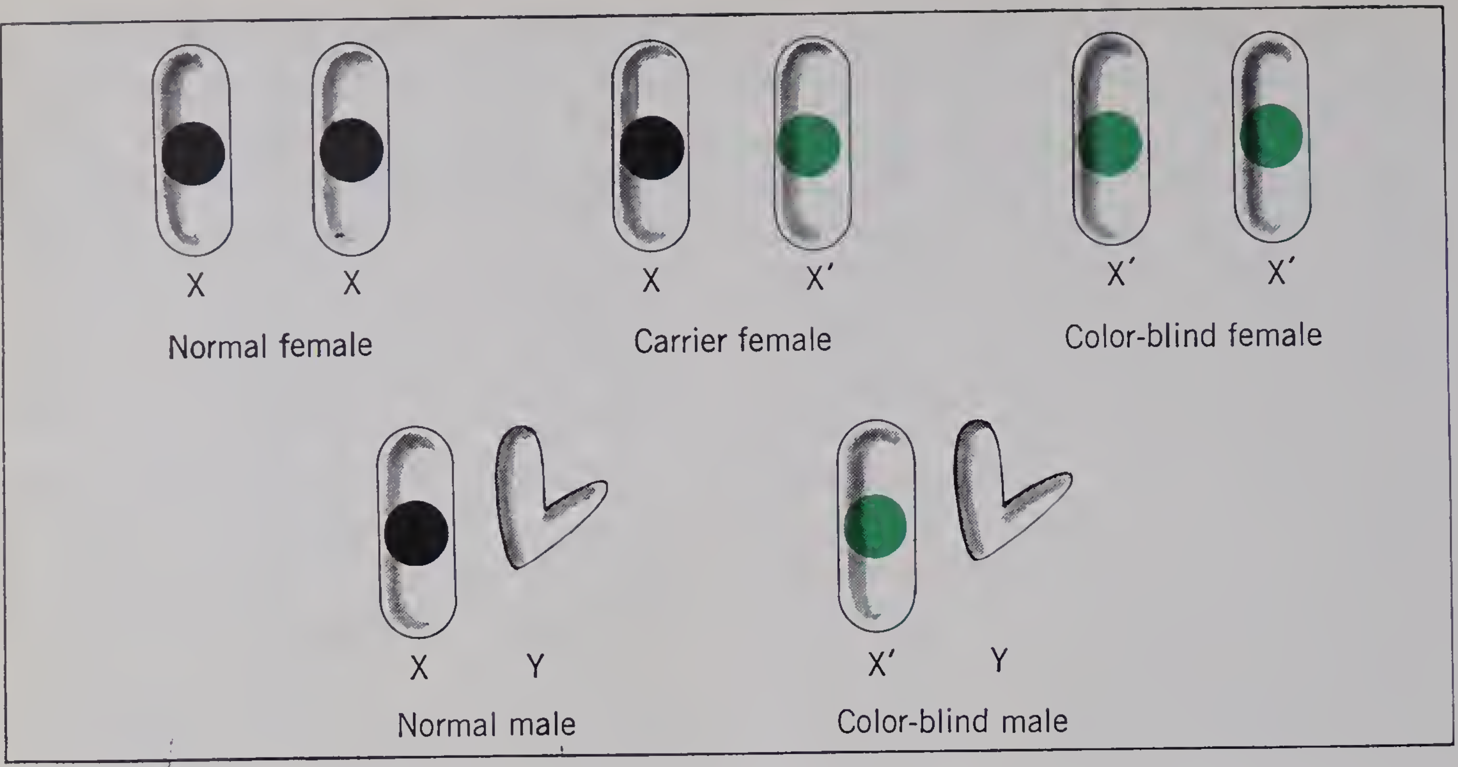
By using a grid we can show how a mother who is a carrier of color blindness but who has normal vision might have a son who is color blind, even though the father has normal vision.

The results of this cross indicate that ¼ of the offspring would be normal females, ¼ carrier females, ¼ normal males, and ¼ color-blind males. Perhaps you can determine a cross in which a color-blind female might result.

Hemophilia (hee-moh-*fee*-lee-a), or "bleeder's disease," is another sex-linked character similar to color blindness in inheritance. Hemophilia is a condition in which a blood substance necessary for clotting is not produced because of the lack of the gene necessary for its formation. Because of the lack of this clotting substance, victims of hemophilia bleed severely and may even die from loss of blood as a result of wounds which would be slight in a normal person.

INHERITANCE OF COLOR BLINDNESS

Female SEX CHROMOSOMES Male	X^C	X^c
X^C	X^CX^C	X^CX^c
Y	X^CY	X^cY



11-6 The gene for color blindness is indicated in color, and the chromosome that carries it is designated as X′. Notice that two such chromosomes are necessary for a color-blind female while only one is necessary in the case of a color-blind male.

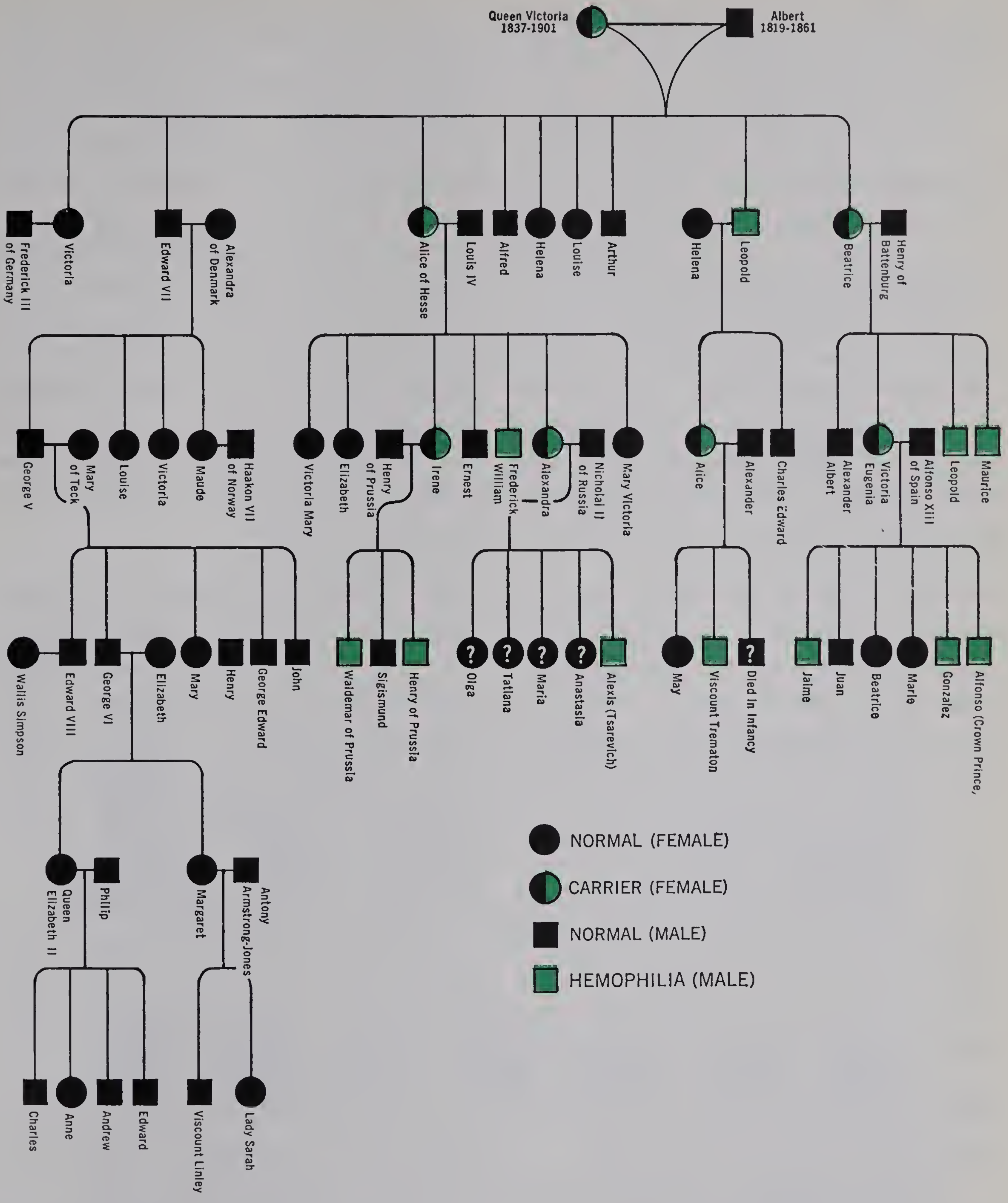
Hemophilia tends to run in families and to appear in males. It can appear in a female only when the father has hemophilia and the mother is a carrier. Several genetic studies have been made of families in which hemophilia has occurred frequently. One of the most famous of these is the study of the family of Queen Victoria, shown in Fig. 11–7. As you examine this family history, notice how many males were hemophiliacs. Then study the chart and note how many females were carriers.

Other characteristics associated with sex. Baldness is an example of a human ***sex-influenced trait.*** The gene for baldness is dominant in males but recessive in females. Thus, a mother may transmit baldness to her son without showing it herself. If we represent the gene for baldness as *B* and the one for normal growth of hair as *b*, then a *Bb* male would be bald, while a *Bb* female would not be. However, *BB* would represent a male or a female with baldness, while *bb* would produce a normal male and female.

Another type of inheritance, which has been investigated in birds more thoroughly than in humans, involves ***sex-limited traits.*** In this type of inheritance certain genes produce a character in one sex or the other, but not in both, even though they are carried in both sexes. It appears that sex-limited characters appear only in the presence of sex hormones.

One example of a sex-limited character is the bright plumage of certain male birds, which does not appear in females of the same species. The roosters of most breeds of chickens develop a large comb and wattles and characteristic male plumage, while hens of the same breed develop a different kind of female plumage. Both result from the action of genes in the presence of sex hormones.

In humans similar sex-limited genes may determine such characteristics as the growth of a beard. A son


Queen Victoria 1837-1901
Albert 1819-1861
Frederick III of Germany
Victoria
Edward VII
Alexandra of Denmark
Alice of Hesse
Louis IV
Alfred
Helena
Louise
Arthur
Helena
Leopold
Beatrice
Henry of Battenburg
George V
Mary of Teck
Louise
Victoria
Maude
Haakon VII of Norway
Victoria Mary
Elizabeth
Henry of Prussia
Irene
Ernest
Frederick William
Alexandra
Nicholai II of Russia
Mary Victoria
Alice
Alexander
Charles Edward
Alexander Albert
Victoria Eugenia
Alfonso XIII of Spain
Leopold
Maurice
Wallis Simpson
Edward VIII
George VI
Elizabeth
Mary
Henry
George Edward
John
Waldemar of Prussia
Sigismund
Henry of Prussia
Olga
Tatiana
Maria
Anastasia
Alexis (Tsarevich)
May
Viscount Trematon
Died in Infancy
Jaime
Juan
Beatrice
Marie
Gonzalez
Alfonso (Crown Prince,
Queen Elizabeth II
Philip
Margaret
Antony Armstrong-Jones
Charles
Anne
Andrew
Edward
Viscount Linley
Lady Sarah
NORMAL (FEMALE)
CARRIER (FEMALE)
NORMAL (MALE)
HEMOPHILIA (MALE)

11-7 The English royal family of Windsor (the family name of Queen Elizabeth) has an interesting hereditary trait — hemophilia.

might inherit a beard characteristic from his mother, even though she did not develop the characteristic because of the lack of male hormones.

Inheritance of eye color and skin color. The inheritance of eye color is governed by multiple alleles. Blue eyes are produced by a single pair of recessive genes. The genes producing brown pigment are dominant. The various shades of iris pigmentation from hazel to light brown or dark brown are apparently the result of the expression of varying numbers of genes for brown pigmentation. Other genes for pigmentation produce shades of gray ranging to green. Loss of the eye pigment genes resulting from mutations produces the pink eye of the albino.

Skin color is thought to be determined by several pairs of genes. Some geneticists suggest that two pairs of alleles are involved. Others believe that four to perhaps as many as eight pairs of genes may function. In any case, the color of the skin from dark brown, medium brown, light brown, and white skin are the result of the expression of varying numbers of genes for skin pigmentation. Other pigment-producing genes are responsible for the yellow skin of oriental peoples and the reddish or bronze skin of many Indians.

Are diseases inherited? The question of whether diseases are inherited is of great importance to the geneticist because of its medical aspect. Many geneticists have explored the possibility that certain diseases that appear to run in families may be related to genes. In infections such as tuberculosis, the disease itself cannot be inherited. However, evidence seems to indicate that chemical conditions in the body tissues important in resistance against infections may be inherited. Lack of this resistance would increase the possibility of contracting the disease sometime during one's life. However, proper precautions can prevent tuberculosis.

On the other hand, diseases resulting from abnormal structure or function of body organs are more likely to be hereditary. Such a disease is sugar diabetes (*diabetes mellitus*) in which certain cells of the pancreas fail to secrete sufficient insulin, a condition we shall discuss more fully in Chapter 44. Diabetes has been found to occur frequently in certain families. It is thought to be due to a recessive gene. However, the disease is not equally serious in all people. Furthermore, regulation of the diet and body weight may prevent or arrest the condition even when the genes are present. There is also evidence that multiple factors may be involved in the inheritance of diabetes. If this is the case, the seriousness of the disease might be determined by the number of genes present.

Case history studies of human families indicate that many other human diseases and disorders may be definitely associated with genes. Among these are respiratory allergies, asthma, bronchitis, nearsightedness, farsightedness, and night-blindness.

Is intelligence inherited? To what extent is intelligence related to genes? This is a very difficult question to answer since no one has yet given an adequate definition of intelligence. We find many families in which parents and children seem to be highly intelligent. Is this a genetic quality, or is it the product of the home, the school, and other environmental influences?

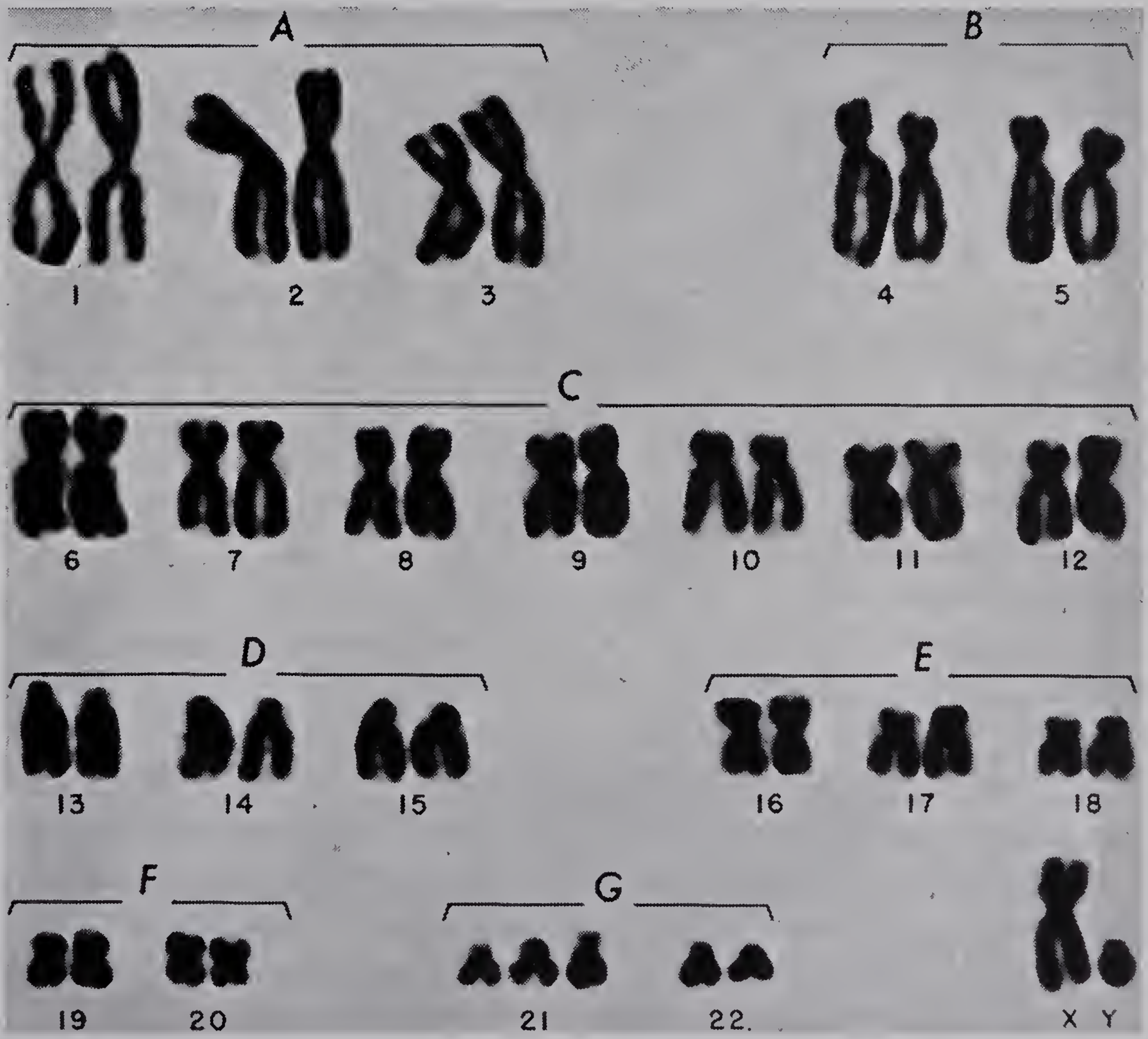
One of the standard methods of measuring intelligence has been a test that involves reasoning, memorizing, calculating, visualizing, word recognition, word usage, and other fundamental thought processes. The score on such an intelligence test is used to determine the *mental age*. Intelligence is then determined by dividing the mental age by the *chronological age*, or age in years. The result, multiplied by 100, is the *intelligence quotient*, or I.Q. An average I.Q. is considered to be 100.

There is some evidence that intelligence is related to genes. Geneticists believe that many alleles must be involved. Identical twins provide the best evidence of such a genetic influence. The similarity between their intelligence test results is striking. There is much less similarity of results between fraternal twins, and still less among other brothers and sisters. The decrease continues as relatives become more distant. Thus, genes and gene combinations, yet undiscovered, must at least share with environmental influences in determining intelligence.

Inheritance of mental disorders. Extensive genetic studies have supplied evidence that several kinds of mental deficiency have a definite genetic basis. Among these are forms of arrested mental development resulting in idiocy. Such deficiencies may be the result of complex chemical disturbances or the lack of certain enzymes associated with mental development. In some cases, these disturbances are the result of mutations.

In recent years biologists have found the genetic basis for *Mongolian idiocy*. This unfortunate condition occurs in about one birth in one thousand in mothers under 35 years of age, but increases to 20 to 30 per thousand (2 to 3 percent) in mothers over 45 years of age.

The genetic basis for Mongolian idiocy was discovered, probably by accident, in studies of human chromosomes. You will recall that the normal chromosome number in humans is 46. However, biologists found that the body cells of some individuals contained 47 chromosomes, while others had only 45. When the body cells of Mongolian idiots were examined, there were always 47 chromosomes present, as shown in Fig. 11–8. Mongolian idi-



11-8 Nondisjunction in Mongolian idiocy. Compare this photograph with Fig. 11-1 and determine the difference in chromosome content. (D. H. Carr and M. L. Barr) ocy, then, seems to result from the presence of an extra chromosome. This extra chromosome is the result of nondisjunction during meiosis, a phenomenon you studied earlier in a vermilion-eyed female *Drosophila*.

Another type of arrested mental development, known as *phenylpyruvic* (fenl-py-*roo*-vik) *idiocy*, is due to the lack of an enzyme. As you learned earlier, genes regulate the production of enzymes. Enzymes in turn regulate the production of amino acids. If a gene or an enzyme in any chemical sequence is lacking, the chain of reactions cannot occur. Phenylpyruvic idiocy is due to the inability of the individual to convert the amino acid phenylalanine to a similar amino acid, tyrosine. The condition is inherited as a simple recessive trait. The enzyme necessary to convert phenylalanine to tyrosine is present in the liver of normal individuals. Those who lack the enzyme cannot oxidize phenylalanine during normal metabolism. Thus, these individuals excrete the unoxidized amino acids from the body in a condition called *phenylketonuria*, or PKU. The inheritance of phenylpyruvic idiocy is further evidence for the one gene-one enzyme concept of gene action. It also illustrates the vital role of enzymes in growth and development, since only one pair of genes and the lack of one enzyme prevents the phenylpyruvic idiot from developing as normal.

Geneticists have much to learn about the relation of genes to mental deficiencies. Is there some genetic lack in the more than three million feebleminded people in the United States today? Are certain mental illnesses related to genes? Manic-depressive psychosis is thought to be hereditary, at least to some degree. It seems to be related to a dominant gene, although the presence of the gene may merely produce a tendency which can be avoided by environmental influences. Similarly, a tendency to develop schizophrenia may be associated with genes.

IN CONCLUSION

"Your genes are showing" might be an appropriate concluding statement to a study of human genetics. They do show in many traits and features. Together with environmental influences, genes have been at work through the years, determining what kind of a person you are.

Human genetics is of great importance in many aspects of human life. True, you cannot alter your genes, but you can make the most of your inheritance. Few people actually achieve this goal. From another standpoint, our knowledge of human genetics has opened a new door for medical contribution to humanity. "Living with genes" may mean compensating for some genetic lack or problem. It might mean supplying a missing substance in the body chemistry or preventing the development of an undesirable genetic trait or problem, such as diabetes.

We now shift our study to the application of the principles of genetics to scientific plant and animal breeding. In this area of applied genetics, we have made astounding progress on our farms and ranches, our orchards, gardens, and vineyards.

BIOLOGICALLY SPEAKING

agglutinogen
fraternal twins
gene frequency
gene pool
identical twins
multiple alleles
population genetics
Rh factor
sex-influenced trait
sex-limited trait

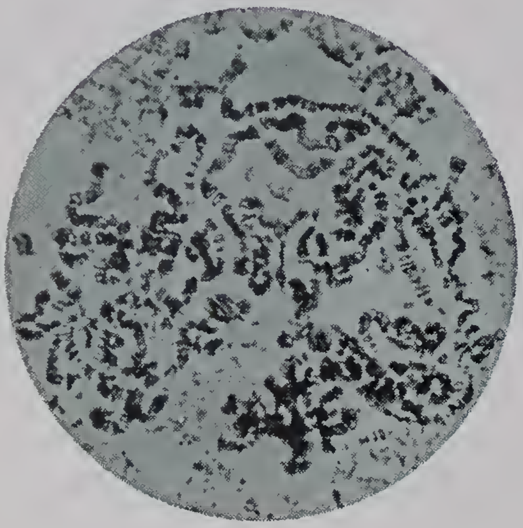
QUESTIONS FOR REVIEW

1. List several of your physical characteristics you believe to be produced by gene action.
2. Generally, what is population genetics?
3. How may PTC papers be used as a basis for sampling a population?
4. What is a gene pool?
5. When is a gene pool considered stable?
6. Distinguish between fraternal twins and identical twins.
7. Explain how A and B red corpuscle agglutinogens establish four basic human blood groups.
8. What are multiple alleles?
9. In what way does the inheritance of blood type involve multiple alleles?
10. Generally, what are the Rh factors?
11. Why is color blindness more frequent in males than in females?
12. In what respect might we consider a gene for hemophilia a lethal gene?
13. Distinguish between sex-influenced and sex-limited traits, giving an example of each.
14. Explain how the inheritance of eye color involves multiple alleles.
15. Give several examples of a possible genetic relation to human diseases.
16. Explain how an intelligence quotient is determined.
17. What chromosome abnormality is believed to be the cause of Mongolian idiocy?
18. What specific biochemical deficiency is believed to cause phenylpyruvic idiocy?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss environmental influences as complicating factors in the study of human genetics.
2. Discuss the limitations of genetic studies in individual families.
3. How is random sampling applied to studies in population genetics?
4. Discuss various reasons for the shifting of genes in a gene pool.
5. How may identical twins supply valuable data in the study of human genetics?
6. Discuss various problems in establishing proof of gene action in producing intelligence.
7. How does phenylpyruvic idiocy bear out the one gene-one enzyme hypothesis?

CHAPTER 12



APPLIED GENETICS

Plant and animal breeding — a time-honored practice. Selective breeding of plants and animals is an old practice. For centuries man has made a constant effort to improve the varieties of plants and animals that supply his daily needs. Wheat was grown as a cereal crop by the early Egyptians. Flowers, fruit trees, fowl, sheep, goats, and cattle have been bred for domestication longer than recorded history.

The science of genetics originated largely to explain the results of plant and animal breeding. Breeding was a practice of chance selection rather than scientific application of principles. With the development of genetics as a science, established laws have greatly improved the efficiency of the process. We must remember, however, that the breeding of a plant or animal involves the crossing of not one or two, but hundreds of different characteristics. While the laws of heredity apply, the results are not always as predictable as they were for Mendel's seven traits in peas.

Luther Burbank, the genius of California. Plant breeding will always be associated with the genius of Luther Burbank. He produced many new and different plants on his farm in California.

Burbank's brilliant work began in the summer of 1871 in his native Massachusetts. While a young man he was examining a crop of potatoes one day and happened to notice a fruit maturing on one of the plants. This was an unusual occurrence because the potato plant flowers regularly but seldom bears fruit. New plants are grown from cuttings rather than from actual seeds. Burbank saved that fruit. When the seeds ripened he planted each one in a separate hill. After the plants matured, he dug up the potatoes and discovered that those from each plant were different. Some were large, some were small. Some hills had many tubers, while others had only a few. One hill had far better potatoes than any of the others. These were large, smooth, and numerous. Burbank sold them to a gardener for $150 — his first profit from plant breeding. They were named Burbank potatoes in his honor, and were the first of a strain that was destined to become popular all over the country.

With the profit from his first achievement, Burbank bought a ticket to California, where he established the farm that made him famous. From his experimental gardens came such varieties as the Shasta daisy and a new strain of poppies. By combining various fruits, he produced the plumcot, pitless plum, and the improved peach plum. Another of his famous develop

12-1 Luther Burbank — the genius of plant breeding. He is probably holding one of the many root crops which his work did so much to improve. (Bettmann Archive)

ments is the thin-shelled walnut. The spineless cactus, used as fodder for cattle, is still another of his achievements.

Objectives in plant breeding. The plant breeder has several purposes in producing new strains or varieties of plants. One of the chief objectives is the production of *more desirable varieties.* Such characteristics as large fruit, large and abundant seeds, vigorous growth, early maturation of fruit, large leaf area in leafy vegetables, and vigorous root growth in root crops are highly profitable. Plant breeders work constantly to improve the quality and quantity of the yield of all crop plants. In addition to the nature of the yield, resistance to disease is highly important. Plant breeders also have been able to produce many varieties of *disease-resistant crops.*

A third objective is an *extension of crop areas* through the production of new varieties. Wheat is an example of this extension through plant breeding. Varieties of spring wheat grow well in the northern sections of the nation, while winter wheat favors the climate of the central states. Wheat growing has been extended even to the Great Plains by the production of varieties of hard wheat. In a similar way other crops that were once limited to small areas because of climatic requirements or soil conditions have now been extended to many other regions in the form of new varieties.

Plant breeders have even been able to develop entirely *different kinds of plants.* The new plant may be the result of crossing two strains or varieties or two closely related species.

Obtaining desirable varieties by mass selection. As the name implies, *mass selection* consists of the careful selection of parent plants from a great number of individuals. Burbank practiced mass selection when he discovered his famous potato. He selected the most ideal plant from all those he grew from seed. The farmer who selects seed from his own crop always picks the most desirable plants for propagation. Thus he takes advantage of any natural, desirable variations that occur.

Mass selection is important, too, in the production of disease-resistant strains of plants. To show how mass selection operates, let us assume that a cabbage disease has swept into an area, resulting in the destruction of almost all the crop. As we examine the acres of diseased plants, we find two or three plants that, because of some unknown

12-2 One way to control the deadly blue mold of tobacco is by breeding disease-resistant strains. Here a technician is shown putting pollen from a wild species, which is immune to the disease, on the pistil of a cultivated variety, which is susceptible. (USDA)

variation, have withstood the disease. We carefully select the seeds from these plants and sow them the following season. Disease again strikes the crops, but a few more plants remain than the year before. These plants have inherited the favorable genetic trait from the parent. Again, we use these plants for seed in the following season. Each year more and more plants withstand the disease. The genetic trait for disease resistance, present in the original plants, has become more common in the offspring as they have been selected and allowed to breed. Finally an entire strain is developed in which this character appears.

What is outbreeding? We define *outbreeding* as the crossing of two different varieties to obtain a new one. This is also called *hybridization*. It is like mass selection in some ways because desirable traits are always sought. But it is a more rapid way of getting the desired results than selection of natural variations.

In hybridization, characteristics of two unlike but closely related parents are combined in a new individual by artificial cross-breeding. In getting a new hybrid strain, we might choose one parent because of vigorous growth. The other one might be selected because of the fine quality of its fruit or flower. Often a hybrid possesses qualities not shown in either parent, because of a new combination of genes. This ***hybrid vigor*** may include increased size, fruitfulness, speed of development, and resistance to disease, insect pests, and climatic extremes.

Line breeding – the opposite of hybridization. After the desired characteristics have been obtained by mass selection or hybridization, the next step is to

12-3 Hybrid vigor is expressed in hybrid corn. Note the large size of the plants and the great yield. (USDA) propagate these new and different plants. This is a simple matter when vegetative multiplication is involved, because such asexual reproduction does not involve the recombination of genes.

After Burbank had discovered his potato, propagation was simple. He used cuttings from the potato in order to produce more plants exactly like the parent. Had he been forced to grow more potatoes from seed, the situation would have been quite different because chromosomes from two parents would have been involved. In the same way, the grower can propagate a new variety of apple, peach, iris, or rose by grafting, cutting, or budding without altering the hereditary make-up.

In plants that are propagated by seeds, like corn and wheat, the problem is more difficult. Seed production involves a mixing of numerous characters. Plants produced from seeds are not necessarily like the parent, especially when they are crop plants that have been crossed by man for centuries.

This difficulty can be overcome by generations of *line breeding*, or ***inbreeding.*** This is the opposite of hybridization, or outbreeding. Self-pollination is carried on to avoid introducing any new characteristics from a new plant. Seeds resulting from self-pollination are planted and all individuals of the new generation are carefully sorted. Only those with the desired characteristics of the parent are selected as seed plants for the next generation. Again, self-pollination is carried on, after which the resulting plants are sorted with the greatest possible care.

As you repeat this breeding method generation after generation, more and more plants bear the desired characteristics. Eventually a pure strain that will be true to seed is established and is ready for the market. Even then all plants may not produce the pure-strain characteristics, but these individuals can be readily sorted out.

The production of hybrid corn. Years ago a farmer saved some of the best ears from his corn crop as seed for the next year. By the process of mass selection he tried to produce more corn like his best plants of the previous season. But the plants that bore these ears were so mixed in their heredity that only some of the kernels bore the genes that had made them productive. And with no control over pollination, the farmer had no idea about the quality of the other parent. The seeds on a single ear might produce many different varieties of corn, some good and some poor. Some of the kernels might have resulted from self-pollination, while others were the result of cross-pollination from fields some distance away. It was not unusual to find ears of corn with a mixture of yellow, white, and red kernels. Often sweet corn and popcorn were mixed with kernels of field corn. Under conditions like these a yield of 20 to 40 bushels per acre was all that could be expected.

Today hybrid varieties are produced by scientifically controlled artificial pollination. When two varieties of corn are cross-pollinated, the offspring are usually more vigorous than either parent. One of the reasons for this seems to be that the desirable dominant characteristics from both parents mask many of the undesirable recessives. The hybrids produced today yield from 100 to 180 bushels of corn per acre. These hybrids have large root systems, sturdy stalks, broad leaves, and large ears. Today the need is for full, long ears.

Much of hybrid corn planted today is the result of a double-cross in which four pure-line parents are mixed in two

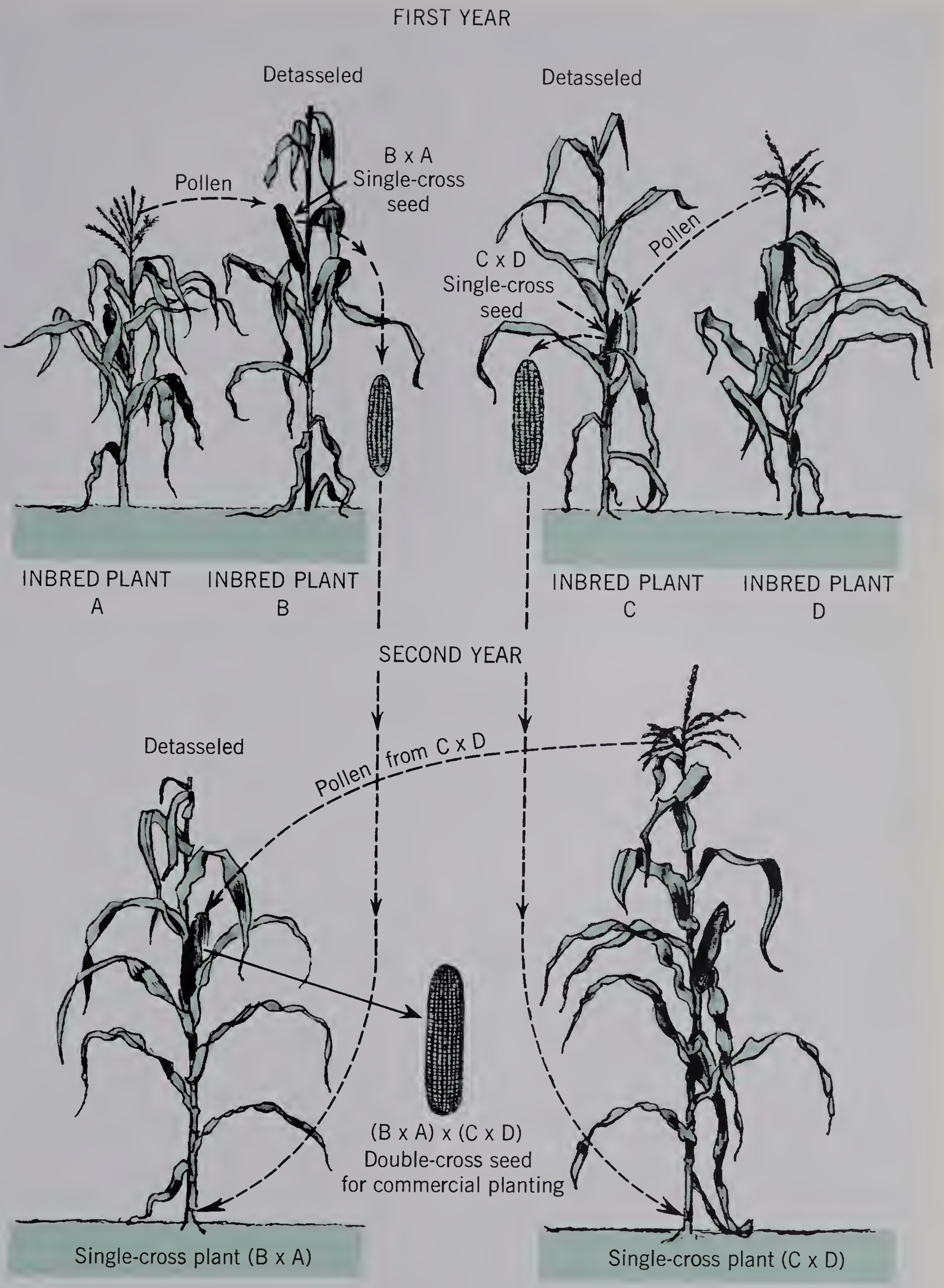
12-4 Controlled pollination of corn. To produce the necessary inbred lines required for hybridizing, care must be taken to be sure no natural pollination occurs. The photograph at the top shows the plastic bag which is used to cover the stigmas ("silk") so they will not be contaminated by other pollen. At the bottom pollen previously collected from another plant is carefully blown on the stigmas and the bag is slipped back into place. (Funk Bros. Seed Co.)

crosses. Each pure-line parent has been selected because of its vigor, resistance to disease, or some other desirable trait. Plants resulting from the double-cross, however, are superior to any of the parent strains.

Figure 12–5 shows how hybrid corn is produced by the double-cross method. Four inbred plants, designated as A, B, C, and D, serve as the foundation. These varieties are the result of controlled self-pollination, or line breeding. This is accomplished by covering the developing ears with sacks until the silks are ready to receive pollen. Then pollen collected from the same plant is dusted onto the silks. The plant breeder carefully avoids any contamination of these inbred varieties. During the first cross, plant A is crossed with plant B, which produces a single-cross hybrid, plant AB. In making this cross, the tassel from plant B is removed and the ear is covered with a bag. When the silks are mature, they are dusted with pollen from plant A. A similar first cross is made between plant C and plant D, resulting in a single-cross hybrid, plant CD. The following season plant AB is detasseled. The developing ear is covered. This plant is cross-pollinated with plant CD. Kernels resulting from this double-cross are designated as ABCD.

This seed is sold to the farmer for planting. However, he cannot plant the seed produced by this hybrid corn because the genes will sort out in new combinations in the next generation. He might get plants that would have different characteristics from those of the hybrid parents.

Producing new plants by crossing different species. One of the best known of Burbank's plant varieties is the Shasta daisy. He produced this beautiful garden flower by crossing a native oxeye daisy with a European variety. In a cross between a plum and an apricot, he produced the plumcot. Another hybrid


FIRST YEAR
Detasseled
Detasseled
Pollen
B x A
Single-cross
seed
C x D
Single-cross
seed
Pollen
INBRED PLANT
A
INBRED PLANT
B
INBRED PLANT
C
INBRED PLANT
D
SECOND YEAR
Detasseled
Pollen from C x D
(B x A) x (C x D)
Double-cross seed
for commercial planting
Single-cross plant (B x A)
Single-cross plant (C x D)

12-5 This diagram shows the method of crossing inbred corn plants and of crossing the resulting single crosses to produce double-cross hybrid seed. The four plants labeled A, B, C, and D represent the products of four different inbred lines. Strain A is crossed with strain B (A furnished the tassel and B was detasseled). Likewise, strains C and D are crossed. The F_1 generations of these two lines are then crossed to produce the hybrid corn seed which is used by farmers today. (U. S. Department of Agriculture)

12-6 Left: an iris having the normal chromosome number. Right: a mutant variety having the tetraploid number. (Walter Dawn)

plant was produced by crossing the squash and the pumpkin. One of Burbank's last experiments was an attempt to cross a tomato and a potato to produce a dual-purpose plant that would bear fruit above ground all season and form tubers that could be dug at the end of the season. Unfortunately such a cross was never perfected.

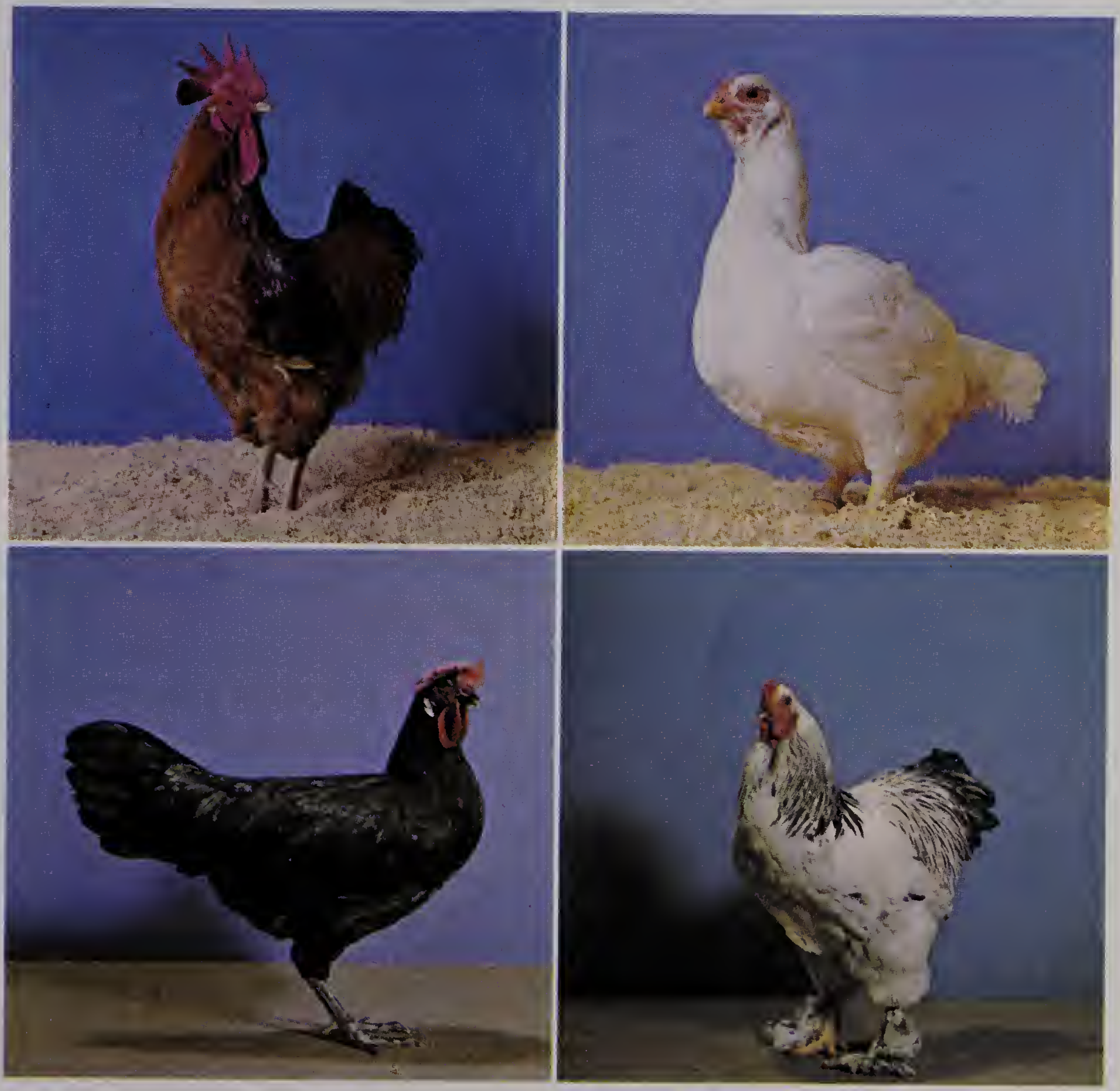
Plant varieties resulting from mutations. While examining a bed of white tea roses one day, a grower happened to notice a branch that had produced a pink flower. He carefully removed the branch and set it in a cutting bed. The plant that grew from the branch bore all pink flowers. These were budded onto understock and propagated as a *bud-mutant*, or ***sport***, of the white rose. Such somatic gene mutations occur from time to time in plants. In the tea rose, a color gene had mutated in a cell of the stem. All tissues of the branch that developed possessed the mutant trait.

Other varieties that have resulted from a bud-mutation include the California navel orange, the Delicious apple, and the smooth-skinned peach, or nectarine.

Plant varieties with chromosomal aberrations. Have you ever noticed blueberries on a fruit counter that are twice as large as native blueberries? These blueberries have a double set of chromosomes. This condition, in which plants have some multiple of the diploid number of chromosomes, is called ***polyploidy*** (*pahl*-i-ploid-ee). Other fruits that have been produced by plants with multiple chromosome numbers include varieties of plums, cherries, grapes, strawberries, and cranberries. A similar increase in the chromosome number occurred in the McIntosh apple. Normal McIntosh apple trees usually have 17 pairs; or 34 chromosomes. However, one variety with a fruit more than twice as large as the normal McIntosh has four sets of chromosomes (the *tetraploid* number $4n$), or 68 in all.

A polyploid with an even number of chromosome pairs (4*n*, 6*n*, 8*n*, etc.) is usually fertile. However, the formation of gametes is interfered with in polyploids having an odd number of chromosome pairs (3*n*, 5*n*, 7*n*, etc.). The lack of fertility is not a handicap in obtaining new specimens with the same genetic makeup. The plant breeder can produce these with cuttings and grafting.

It has been discovered recently that polyploidy can be produced artificially by the drug ***colchicine*** (*kahl*-chi-seen). When shoots of plants are put in a weak solution of colchicine, their chromosome number is often doubled. The drug is also available in salve form for use on buds of plants. Blueberries, lilies, and cabbage are a few plants that have been improved by its application. Even



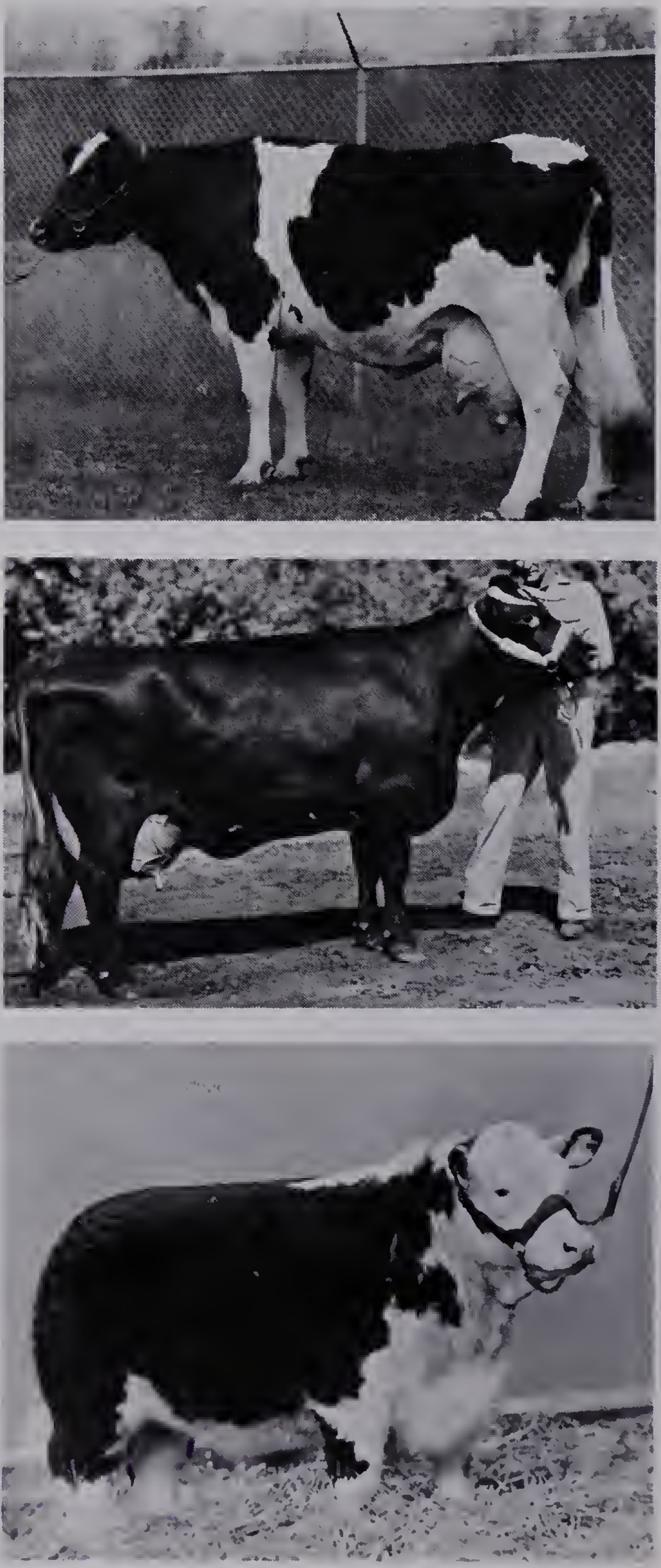
12-7 Selective breeding has produced the poultry shown here. The New Hampshire Red (top left) is suitable for both egg and meat production. The White Cornish and the Light Brahma (top and bottom right) have both been bred for meat. The Black Minorca (bottom left) is suitable for egg production. (Grant Heilman) interspecies can be produced by using colchicine. A cross between the ordinary cabbage, with 20 chromosomes, and the Chinese cabbage, with 18 chromosomes, yields a new type with only 19 chromosomes. This type is sterile. After plant breeders treated it with colchicine, it had 38 chromosomes, but it continued to be sterile. But when plant breeders crossed this plant with a rutabaga having 38 chromosomes, a new type of cabbage was produced. It also had 38 chromosomes, but it was fertile and bred true.

Many years ago almost all garden iris plants were diploid, while most of the modern ones are tetraploid. The less desirable Einkorn wheat is diploid, but the more desirable Emmer wheat is tetraploid, while the vulgare wheat is 6*n*. The large and beautiful varieties of roses include almost every multiple of chromosomes up to 8*n*.

Animal breeding. The principles used in plant breeding apply to animal breeding as well. Mass selection has long been a method of producing highly desirable breeds of animals.

The results of years of selective breeding are well illustrated in the modern breeds of poultry. The Leghorn, for example, has been bred for its ability to lay large numbers of eggs. All its energies are directed toward egg production rather than the production of body flesh. The Plymouth Rock has been developed as a dual-purpose fowl and is ideal for egg production and meat. Large breeds, like the Brahma, Cochin, and Cornish, are famous for their delicious meat rather than for egg production.

The modern turkey, with massive body and broad breast covered with thick layers of white meat, is quite a contrast to the slender bird the Pilgrims found in the New England forest. The modern turkey has been bred for the highest possible flesh production. It spends its life, often on wire, eating a scientifically prepared diet and building



12-8 Three breeds of cattle. Top: an important milk breed, the Holstein-Friesian cow; middle: a dual-purpose breed for both milk and meat, the Milking Shorthorn; bottom: a prime beef breed, the Hereford steer. (Top: USDA; middle: American Milking Shorthorn Society; bottom: American Hereford Association) up large, little-used muscles, better suited to being eaten than to flying and perching high in trees.

Improvement in livestock. Using similar selective breeding methods, domestic cattle have been developed along two entirely different lines. Aberdeen-Angus, Hereford, and Shorthorn are breeds of beef cattle. Their low, broad, stocky bodies provide high-quality steaks and roasts for the nation's markets. Dairy breeds, including the Jersey, Guernsey, Ayrshire, Holstein-Friesian, and Brown Swiss have been bred as milk producers. A breed of Shorthorns known as Milking Shorthorns, as well as Red Poll cattle, are classified as dual-purpose breeds because they were developed for milk production as well as beef.

Swine raising is one of the most important divisions of American agriculture, especially in the Corn Belt. Heavy, or lard, type breeds include the Poland China and Berkshire, Hampshire, and Duroc-Jersey. The Yorkshire and Tamworth hogs have long slender bodies and are classified as lean, or bacon, type hogs.

In livestock breeding, the records of outstanding individuals used in breeding are kept in pedigree and registration papers. Purebred animals may be registered at the headquarters of their respective breeds. Papers must include the names and registration numbers of both sire (male) and dam (female) as well as part of the ancestry. In this manner different strains of the same breed may be crossed without the danger of introducing undesirable characteristics or losing any good qualities.

The crossing of two different species. The mule is an animal that has resulted from the crossing of two entirely different species. This hardy, useful animal is produced by crossing a female horse with a male donkey. The size is inherited from the horse. From the donkey the mule inherits long ears, surefootedness, great endurance, and the ability to live on rough food and to endure hardships. However, with all of its hybrid vigor, the mule is usually sterile — that is, unable to reproduce.

Several strains have resulted from crosses between Brahman cattle from India and domestic breeds. Tourists in

12-9 This hybrid Brangus bull combines the heat-resistant characteristics of the Brahman with the excellent beef qualities of the Aberdeen-Angus. (USDA) the southern and southwestern states are often surprised to see these large gray or brownish animals with long, drooping ears and shoulder humps. Brahman cattle can endure the hot, humid climate of the Gulf States as well as the dry summer heat of the Southwest much better than domestic breeds of beef cattle. In addition they resist disease and insect attacks.

A cross between Brahman and Aberdeen-Angus cattle produced Brangus cattle, one of the most popular of the Brahman crosses. The Braford is another crossbreed with Brahman and Hereford cattle as parent stock.

IN CONCLUSION

Scientific breeding has brought rust-resistant asters to flower beds of your home and city parks. Roses in clusters, long-stemmed tea roses, and climbing roses in great variety leave the growers by tens of thousands each season to beautify our gardens. Just name a size and color of tomato and the time in the summer you want it to ripen and a grower will supply it to you. Beef cattle and dairy cattle, fat hogs and lean hogs, horses for work and horses for pleasure — we have them all.

While in this chapter we have discussed man's artificial selection of plant and animal traits, in the next we shall discuss a process of natural selection that has been going on since life began.

BIOLOGICALLY SPEAKING

colchicine
hybrid vigor
inbreeding
mass selection
outbreeding
polyploidy
sport

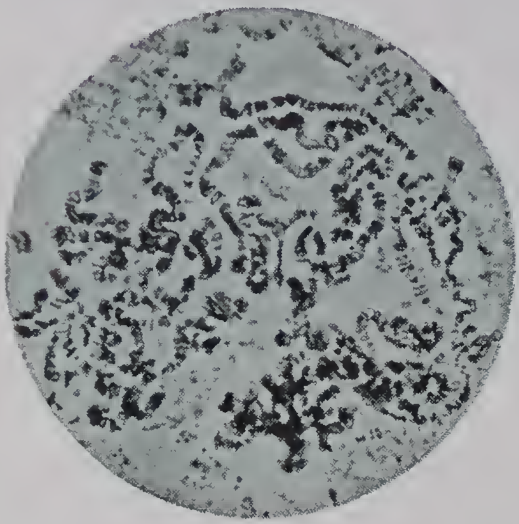
QUESTIONS FOR REVIEW

1. What are four objectives of plant breeding?
2. Why is line breeding practiced in plant and animal breeding?
3. Make a comparison of hybridization and line breeding as to methods and purposes.
4. How many pure-line parents are involved in the production of hybrid seed corn by the double-cross method?
5. Name several hybrid plants produced by the genius of the late Luther Burbank.
6. How is natural cross-pollination prevented during the growing of hybrid corn?
7. Name three general types of chickens and a breed representing each type.
8. Name a dual-purpose breed of cattle.
9. In what respect is the mule a true hybrid animal?
10. Why are Brahman cattle good parent stock for breeding purposes?

APPLYING PRINCIPLES AND CONCEPTS

1. If line breeding is practiced too long, offspring may become weak and inbred. How might this condition be remedied?
2. A farmer does not use seed from his hybrid corn for the next year's crop. Explain why.
3. Outline the method by which poultry breeders have been able to increase egg production by developing 300-egg strains of chickens.
4. What is the importance of pedigrees and registration papers in breeding livestock?

CHAPTER 13



ORGANIC VARIATION

The study of evolution. Biologists have long been aware that living things have changed over the ages. You need only to look at the reconstructed skeleton of a dinosaur to realize that life on earth today is not the same as it was 100 million years ago. ***Geologists,*** or earth scientists, estimate that the earth is approximately five billion years old, and that life has been present for about two billion of these. Fossil evidence indicates that during this time different forms of life have been dominant, and that the simpler forms evolved earlier than the more complex forms of plants and animals. From such evidence they have constructed a geological timetable such as that in Fig. 13–1. As you can see, it is divided into long ***eras,*** which are in turn subdivided into shorter ***periods.***

The study of the changing world of life is called ***evolution.*** Whether evolution has occurred, how and why it has occurred, and whether it is still going on are questions that have perplexed biologists for years. We shall first discuss some evidences other than fossils that indicate that evolution has occurred.

Evidences of common ancestry. In both plants and animals we find parts that are evidently of similar origin and structure, although they may be adapted for very different functions in different species. These parts are called ***homologous*** (hoh-*mahl*-uh-gus) ***structures.*** In many plants leaves are found modified as petals, tendrils, and thorns. Covering tissue of animals may be modified as hoofs, scales, nails, claws, feathers, and hair. The bones of the bird's wing, the front leg of a horse, and the paddle of the whale are so similar in structure that, with slight exceptions, they are given the same names.

In certain animals, structures exist that are well developed and perform an important function; while in other animals a corresponding structure may be present that is poorly developed or not functioning. These remnants are called ***vestigial organs.*** It is believed that such structures are the remains of organs that were well developed in common ancestors and therefore offer further evidence of the development of animal life and its relationship. The appendix of some mammals, for example, is a small structure without any known function. In others that eat a coarse diet with large amounts of cellulose, this pouch serves as an organ to store mixtures of food and enzymes over a long period of time. In rabbits, the appendix is the largest part of the intestine.

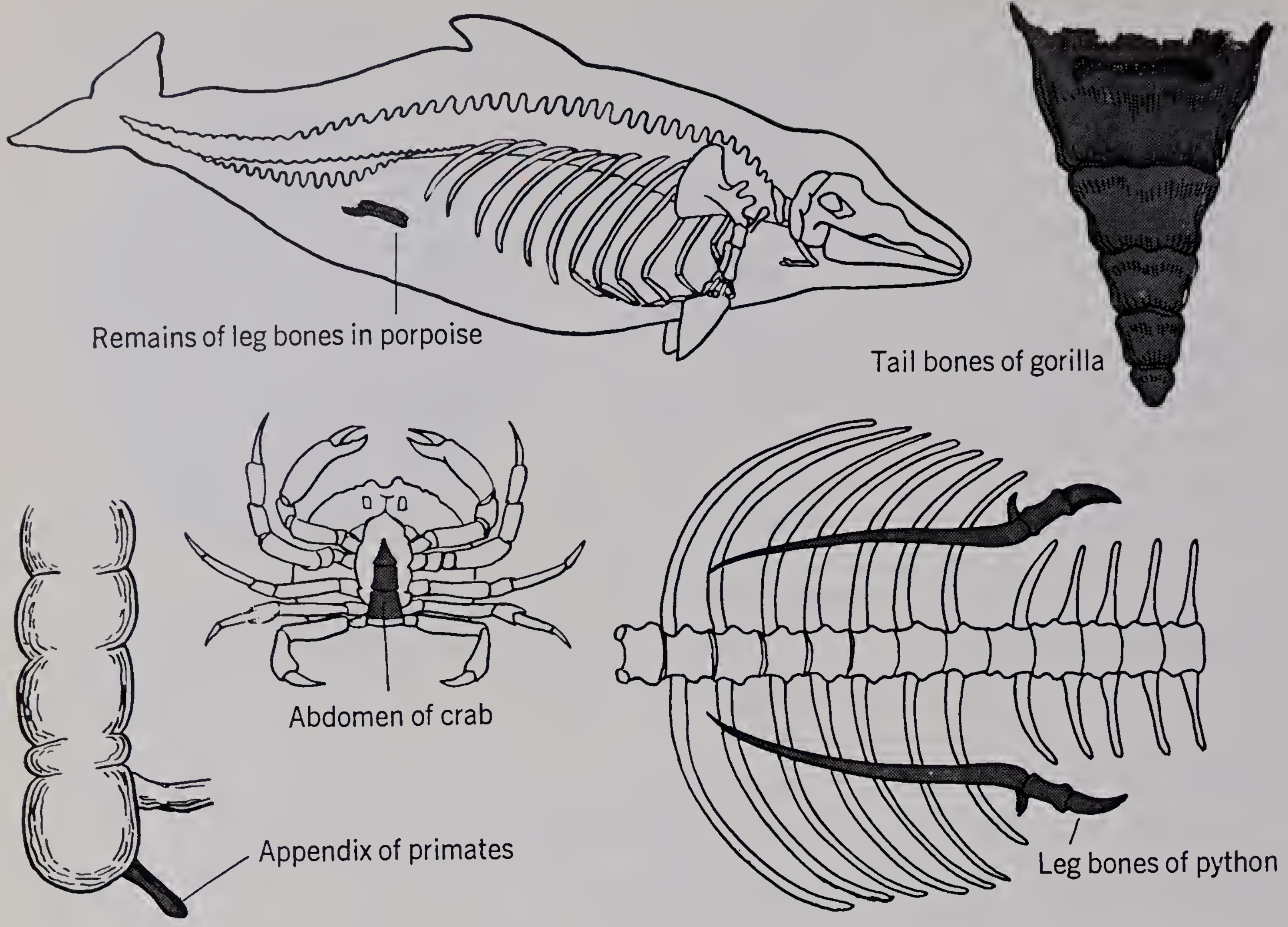
Biologists often have compared the developmental stages of present-day mammalian embryos. The evidence from ***embryology*** seems to indicate that

	PSYCHOZOIC ERA—about 25,000 years
Recent Period	Beginning of man's dominance; domestication of animals
	CENOZOIC ERA—about 60,000,000 years
Pleistocene Period	Ice ages; extinction of mammoth and mastodon; rise of modern horse; man uses fire and makes implements
Pliocene Period	Rise of man; *Pliohippus*
Miocene Period	Saber-toothed tiger; *Protohippus*; whale
Oligocene Period	Primitive anthropoids and *Mesohippus*
Eocene Period	Primitive forms of modern mammals: sloths, armadillos, marsupials, *Eohippus*, rhinoceros
	MESOZOIC ERA—about 125,000,000 years
Cretaceous Period	*Tyrannosaurus* and other dinosaurs became extinct; flowering plants; true trees; modern insects; true birds
Jurassic Period	Giant dinosaurs dominant; birds with teeth; turtles and flying reptiles; egg-laying mammals
Triassic Period	Rise of dinosaurs
	PALEOZOIC ERA—about 350,000,000 years
Permian Period	Rise of insects, spiders, and primitive reptiles; extinction of trilobites and other forms; glacial period
Pennsylvanian Period	Spore-bearing plants; sharks and large amphibians (first land vertebrates); coal formed
Mississippian Period	Rise of crinoids, brachiopods, and sea urchins; dense vegetation on land
Devonian Period	Tree ferns and other land plants; lung fish and primitive amphibians; fish and invertebrates dominant
Silurian Period	First air-breathing animals; crinoids; primitive sharks; scorpions; first land plants
Ordovician Period	Corals and clams; armored fish; starfish; first seaweeds
Cambrian Period	Marine invertebrates: sponges, jellyfish, trilobites, gastropods, brachiopods

Proterozoic Era and Archeozoic Era—about 1,450,000,000 years—Origin of life in form of one-celled organisms; fossil evidence scanty

Total number of years since life began—about 2,000,000,000 years

13-1 The geological timetable. Geological eras are further subdivided into periods. The Pennsylvanian and Mississippian periods are sometimes listed together as the Carboniferous period.



13-2 Nonfunctional vestigial organs are common among animals. These organs provide one source of evidence that living things have changed through the ages.

each animal in its individual development passes through stages that resemble those of remote ancestors.

Not only do certain organisms resemble one another in structure and development, there is also a marked ***similarity in function.*** For instance, all organisms produce nucleic acids, especially DNA, and all use ATP in energy transfer.

Plant and animal breeding provides other evidence that organisms may change. Over 25 kinds of dogs have been developed from wild wolflike ancestors. A dozen kinds of chickens have a common ancestor in the jungle fowl of India. The story of plant and animal breeding, while it does not prove that similar changes have taken place naturally in past ages, does strongly point to that possibility.

Lamarck's theory of evolution. One of the first and most interesting theories to explain evolution was proposed by the French biologist Jean Baptiste Lamarck. His theory, presented in 1801, placed great stress on the environment as the mechanism responsible for change. Actually, Lamarck's idea of evolution involved three theories:

Theory of need — that the production of a new organ or part of a plant or animal results from a need. For example, the early ancestors of the snake had legs and short bodies. But with the changes in land formations, it became necessary for the snake to crawl through narrow places. Then it began to stretch its body and to crawl rather than walk. This assumption formed the basis which Lamarck used to formulate his second theory.

Theory of use and disuse — that organs remain active and strong as long as they are used but disappear gradually with disuse. Lamarck believed that the snakes of each generation continued to stretch and strengthen their bodies. Furthermore, the legs were used less and less because they interfered with crawling, and they finally disappeared.

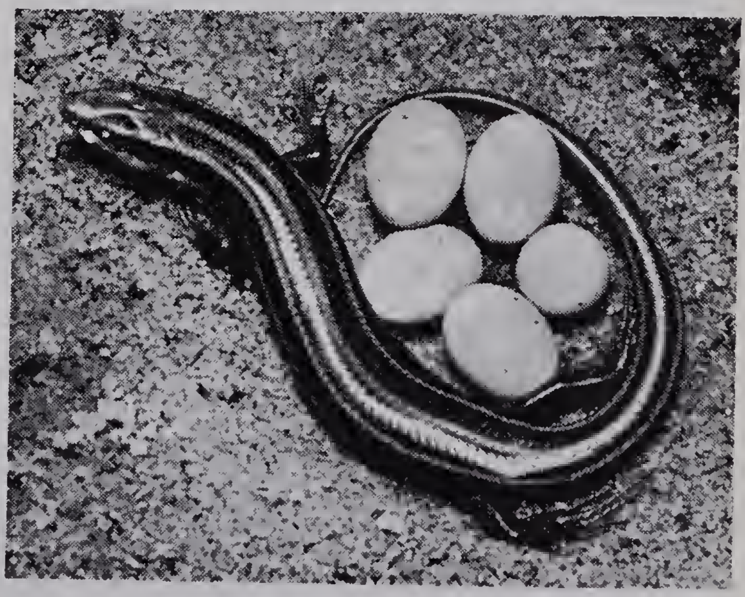
Theory of inheritance of acquired characteristics — that all that has been acquired or changed in the structure of individuals during their life is transmitted by heredity to the next generation. He believed that the modern snakes evolved from the forms that had lost their legs through disuse. Thus they inherited the legless trait from their ancestors.

Lamarck used other examples that he could see in nature to explain his theory of need. He believed that the giraffe evolved from a short-legged, short-necked form. When competition for low-growing grasses became too great, the giraffe began to stretch its neck and forelegs in order to reach the leaves of trees. Each succeeding generation inherited the longer neck resulting from stretching until the trait was inherited by our modern giraffe. Other beliefs held by Lamarck included the idea that frogs and ducks developed webbing in the toes for swimming, and that the heron and other wading birds developed their long legs to keep their bodies out of the water. He attempted to explain the evolution of mammals into birds by suggesting that the hair turned into feathers as certain mammals attempted to fly.

Many biologists have tested Lamarck's theory of inheritance, but each experiment presents further evidence that acquired traits are not inherited. One experimenter tested the theory by cutting off the tails of mice and then mating them. The offspring of the tailless mice had tails. He then cut off the tails of the second generation and mated them. He continued this experiment for 20 generations. The 21st generation still had tails of the same length as the first.

The explanation of evolution given by Lamarck may seem very reasonable. Gradual modifications do appear in species from time to time. Parts of plants and animals do change as a result of use and disuse. For example, an athlete develops strong muscles through use, but muscles become weak from disuse when contained within a cast. There is no evidence, however, that these acquired traits are handed on to offspring.

Darwin's theory of natural selection. In 1859 Charles Darwin, an English scientist, published his *Origin of Species by Natural Selection.* His theory of ***natural selection,*** while confined to biology, has also influenced other branches of science. The chief factors, according to Darwin, that account for the development of new species from common ancestry are listed on page 186.



13-3 According to Lamarck's theory, modern snakes might have developed from a short-legged reptile like the common blue-tailed skink shown here attending her eggs. (Dermid from National Audubon Society)

1. That all organisms produce more offspring than can actually survive.
2. That because of overproduction, there is a constant struggle for existence among individuals.
3. That the individuals of a given species vary.
4. That the fittest, or the best adapted, individuals of a species survive to transmit their traits to the next generation.

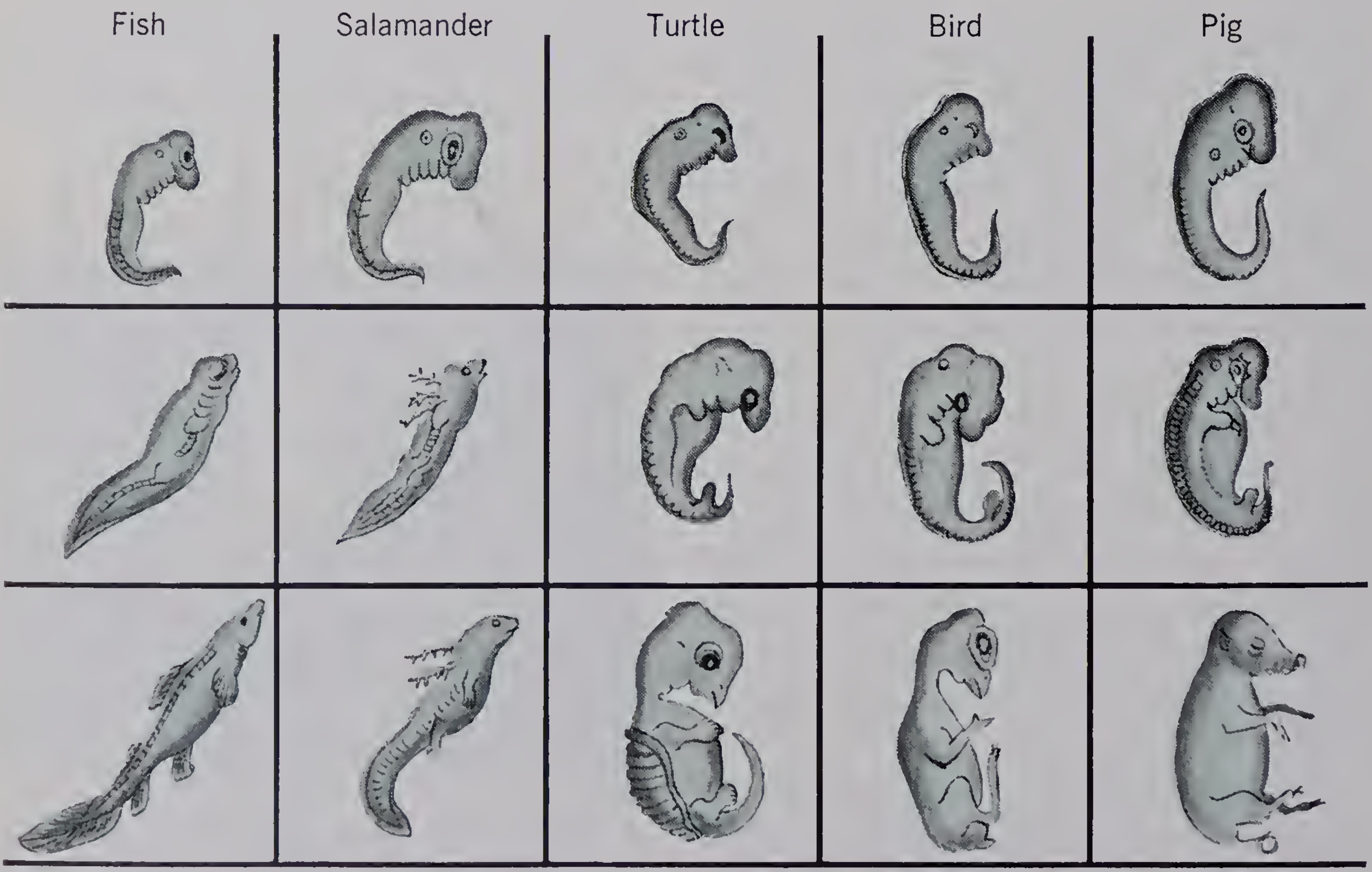
Overproduction. A fern plant may produce 50 million spores each year. If all the spores resulting from this overproduction matured, they would nearly cover North America the second year. A mustard plant produces about 730,000 seeds annually, which, if they all took root and matured, in two years would occupy an area 2,000 times that of the land surface of the earth. The dandelion would do the same in 10 years.

At a single spawning an oyster may shed 114,000,000 eggs. If all these eggs survived, the ocean would be literally filled with oysters. Within five generations there would be more oysters than the estimated number of electrons in the visible universe! There is, however, no such actual increase.

The elephant is considered to have a slow rate of reproduction. An average elephant lives to be 100 years old, breeds from 30 to 90 years, and bears about six young. Yet if all the young from one pair of elephants survived, in 750 years the descendants would number 19,000,000.

The competition for life. We know that in actuality the number of individuals of a species usually changes little in its native environment. In other words, regardless of the rate of reproduction, only a small minority of the original number of offspring reaches maturity.

Each organism seeks food, water,



13-4 Here you see three different stages in the development of five vertebrates. Note the similarities in the very early stages of all five. What differences do you observe?

air, warmth, and space, but only a few can obtain these needs in struggling to survive. This struggle for existence is most intense between members of the same species, as they compete for the same necessities.

Variation among individuals. With the exception of identical twins, every individual varies in some respects from other members of its species. Animal breeders take advantage of this fact when they choose the individuals with desirable characteristics to breed. Nurserymen are able to produce disease-resistant plants and control the size and color of the bloom by careful study and cross-fertilization of particular individuals. The variations within a species furnish the material for nature to use in her selection.

Survival of the fittest. If, among the thousands of dandelion seeds produced, for example, some have better dispersal devices, these will be carried to a distant place where they will be less crowded, and so may survive. Those having poorer adaptations will perish by overcrowding. In so severe a struggle where only a few out of millions may hope to live, very slight variations in speed, or senses, or protection may turn the scale in favor of the better fitted individual. Those with unfavorable variations sooner or later will be wiped out.

In general, offspring resemble their parents. If the parents reach maturity because of special fitness, those of their descendants that inherit most closely the favorable variation will in turn be automatically selected by nature to continue their species. Darwin called this part of his theory ***the survival of the fittest.*** In this way nature is selecting the characteristics of a certain population by favoring even the slightest variation.

Mutation theory of evolution. Mutation as a basis for evolution was proposed by Hugo De Vries, a Dutch botanist, when he presented his mutation theory in 1901. De Vries had found two evening primrose plants that were different from their parent stock and that bred true by producing these variations in offspring. He experimented for many years and found that, from 50,000 specimens of evening primrose, at least 800 plants showed striking noninherited variations that were transmitted to offspring. From his study of the evening primrose, De Vries concluded that similar mutations occurred frequently in other organisms and that this was the basis for the evolution of life through the ages.

Mechanisms of evolution. As we review the work of Lamarck, Darwin, and De Vries, we can see that each made a significant contribution to modern concepts of evolution. Lamarck observed a relation between the organism and its environment. His observation was correct. It was his conclusion that the environment acted directly on the organ-

13-5 This little white fawn is an albino mutant. (Finke from National Audubon Society) ism and produced hereditary changes in relation to need that was in error. Nevertheless, Lamarck did recognize change in living things through the ages, and thus provided evidence of evolution.

Darwin also recognized change, but he reversed the theory Lamarck proposed. He established that the change occurs in the organisms without respect to need. He believed that the environment determines whether a variation improves the chance for survival.

De Vries reinforced Darwin's concepts of variation and survival of the fittest and explained the mechanism of change in terms of mutations and other genetic alterations.

The modern biologist has been able to go much further in exploring the mechanisms of evolution. He has the advantages of recent advances in genetics to account for variations, biochemistry to explain gene action, anatomy and physiology to establish relationships, and ecology to give evidence of environmental relationships, population movements, and other factors operating on a large scale. Generally, we may relate evolution to the following mechanisms: gene mutations, chromosomal mutations, and recombination.

Gene mutations as a cause of change. Mutations have been found in every kind of plant and animal that has been studied genetically — from columbines to fruit flies and mice to men. In gene mutations we find the basic source of variations and the material for evolution. In considering gene mutations as a mechanism in evolution, we must examine their nature and frequency more closely to see how they relate to variations.

How frequently do gene mutations occur? Genes tend to be stable. The DNA molecules composing them tend to replicate time after time without chemical alteration. Still, gene mutations do occur, and at a rate that geneticists have been able to predict. In studies of mutation in corn, geneticists have found that genes for seed color mutate 492 times per 1,000,000 gametes. This would average about one mutation in 2,000 gametes. This may seem to be a very slow rate of mutation. However, when you consider that a single acre of corn contains more than this number of plants, you realize that the frequency of mutations is greater than you might think.

Many gene mutations are so slight that there is no apparent difference in the organism. The fruit fly is believed to contain about 20,000 genes in its haploid chromosome number. Thus the body cells contain as many as 40,000 genes. A mutation in a single gene might not be noticeable. This may account for the fact that change in a population may be detected only over a long period of time, and not from one generation to the next.

Mutant genes are nearly always recessive. For this reason a mutant characteristic does not appear in an offspring in which the other allele is normal. For example, in a pair of genes designated as AA, let us assume that one gene mutates to *a*. The mutant characteristic will not appear in a heterozygous (*Aa*) offspring. However, if the frequency of the mutant gene increases in the population, a homozygous offspring with paired mutant genes (*aa*) may appear and express the new characteristic.

Genes often mutate, then mutate back to the original expression.

Often gene mutations produce a characteristic that cancels the survival chance of an organism. If such a lethal gene is recessive, many individuals in a population may possess the gene without expressing the fatal characteristic. Since homozygous individuals that express the lethal trait die without reproducing, there is a tendency for the frequency of a lethal gene in a population to be reduced. However, additional normal genes may continue to mutate to the lethal gene and perpetuate the problem.

Chromosomal changes. While chromosomal mutations occur less frequently than gene mutations, their effects are usually more noticeable since many genes are involved. In your study of genetics, you found various reasons for changes in chromosomal structure. Generally they include:

1. Polyploidy — gain in the number of pairs of chromosomes resulting in such abnormalities as $3n$ (triploid number) or $4n$ (tetraploid number).
2. Haploidy — loss of one entire set of chromosomes.
3. Nondisjunction — gain or loss of part of a set of chromosomes.
4. Translocation — exchange of parts or segments of chromosomes between a chromosome pair.

These and other changes in chromosome composition and number produce new characteristics in offspring. Thus chromosomal mutations are an important mechanism in variation and resulting evolution of organisms.

Recombination as a source of variation. You will recall, from your study of sexual reproduction, that chromosome pairs separate and reduce from the diploid number ($2n$) to the haploid number (n) in the formation of gametes. During fertilization new combinations of chromosomes are formed as the chromosome number is restored to the diploid number ($2n$). Recombination of chromosomes and genes in sexual reproduction is a mechanism second only to mutations in the production of variations. Furthermore, it is by recombination that mutant characteristics appear as variations in populations.

To show how recombination greatly hastens the appearance of a new characteristic, let us again represent a pair of alleles as AA. One of these genes mutates. The gamete containing this mutant gene unites with a gamete containing a normal allele, producing the gene pair A*a*. Since the mutant gene is recessive, the characteristic will not appear in this individual. If this organism were to reproduce asexually, all offspring would be identical with the parent. The only chance for the variation (*a*) to appear would be for the second gene of the pair (A) to mutate, thus producing the alleles *aa*. The chance of this happening in an organism has been calculated to be about one in 10 billion!

Now consider what sexual reproduction and recombination could accomplish in this example. When the pair of alleles A and *a* separate during meiosis, half of the gametes produced will receive A, while the other half will receive the mutant gene *a*. The new characteristic will not appear in the first generation because the gene *a* must combine with a normal gene A. However, the mutant gene *a* is increasing in frequency. It is now present in half the offspring. As these heterozygous offspring interbreed, they will produce one-fourth AA, one-half A*a*, and one-fourth *aa*, as you determined earlier in a monohybrid cross. Thus one fourth of the offspring will express the mutation. If this characteristic is favorable to survival of these organisms, the mutant gene *a* will increase in frequency in the population as a result of selection. In time all members of the population may possess the mutant characteristic.

Variation, change, and survival. Mutations, chromosomal changes, and recombination provide the genetic basis for variation in organisms. But it is the environment that determines whether variations are favorable to survival. Thus, the environment determines the direction as well as the rate of evolution.

Isn't it logical to assume that a population already established in a given environment is well adjusted to the conditions of that environment? Such a population is the result of natural selection and survival of the fittest over a long period of time during which undesirable variants were eliminated. As long as the environment remains unchanged, it is unlikely that further genetic variations will improve the already adjusted population. But what if the environment were altered? Then, genetic variations might improve the chances of survival and lead to the establishment of a new variety within a species or even to a new species. Changes in environmental conditions may occur in two ways:

1. Migration of an organism to another locality.
2. Change in the environmental conditions in a given locality.

Migration, variation, and the benefit of change. When ***migration*** occurs so that individuals of a population occupy new areas and interbreed with other populations of the same species, new gene combinations are formed. Let us assume that several members of an animal population migrate to a new area. They take with them certain combinations of genes characteristic of the population of which they have been a part. Their arrival in a new area introduces genetic characteristics that have been absent in this population. By interbreeding, their offspring are also receiving different genes from the new population. The genetic makeup of this entire population may be altered by the migrating organisms. Thus, one result of migration is the production of variations through new gene combinations.

There is another important result. Migration takes plants and animals into new and different environments. This introduces the *benefit* of change. New characteristics that appear in offspring through mutations and recombinations of genes may result in adaptations that are favorable to the new environment.

Migration and selection in animal populations. The migration and redistribution of camels in early times is a good example of the spreading of a population and selection. At one time camels in various forms were found throughout Asia, Europe, North America, Central America, and South America. Biologists believe they had their origin in North America and spread to Asia when the two continents were connected by a land bridge which at that time spread across the Bering Strait region. Such a land bridge that acts as a pathway for migrating animals is spoken of as a ***corridor.*** The camel migrations extended through North America and Central America to South America. Then, with the coming of the Ice Age, the camel population was eliminated in most areas. This resulted in widely separated camel populations. Today, we have the Asian camel with two humps and the African (Arabian) camel with one hump. Both are well adapted for life in the desert. Relatives in far-off South America evolved into quite a different animal, lacking a hump but sure-footed and protected with a dense coat of hair that adapts it for life in the rocky, mountainous area — the South American llama.

The individual variations among

the camel populations that reached the Andes were probably not very great. But the ones with the slightly heavier coat had a better chance to survive cold winters and to reproduce the following year. Also, the animals with shorter legs and sure-footedness had a better chance to survive by running away from enemies. The animals that did not possess these favorable variations were eventually wiped out.

The movement of organisms to new environments sometimes involves strange and interesting methods and devices. A mouse may float across a wide body of water on a log and reach a new environment. If other mice are present in the new environment and are capable of interbreeding with the new arrival, new gene combinations may be formed and mice may strike out in a new evolutionary direction. We refer to such distribution over strong barriers as ***sweepstakes dispersal.***

The peppered moth and the impact of environmental change. A moth population in England affords us one of the best examples of the impact of a change in the environment on a species. The peppered moth (*Biston betularia*) is native to the region of Manchester, a British industrial city. Two British scientists, R. A. Fisher and E. B. Ford, conducted the original investigation of a color change that occurred in this moth within a period of just 50 years. More recent studies were conducted by Professor H. B. D. Kettlewell. The result of these investigations has become a classic example of evolution in action.

Prior to 1845 the peppered moth was light colored with dark blotches and spots. It could hardly be seen when resting on the light gray bark of trees. Then, in 1845, a black color variation of the peppered moth was captured in Manchester. A mutation had occurred in a gene determining coloration. Was this a favorable mutation? You would expect a black moth resting on light bark to be an easy prey for a bird. But something else was happening in Manchester. The city was rapidly becoming an industrial center. Smoke poured from factory chimneys, and soot turned the light-colored bark of the trees nearly black. The black moths could hardly be seen on the dark, sooty bark. With this environmental change the light moths became easy prey for birds. In the period from 1845 to 1895, the black peppered moth population increased from one known individual to 99 percent of the population!

13-6 The African, or Arabian, camel has only one hump, whereas the Asian camel has two. (Top: Arabian American Oil Co.; bottom: Ewing Galloway)

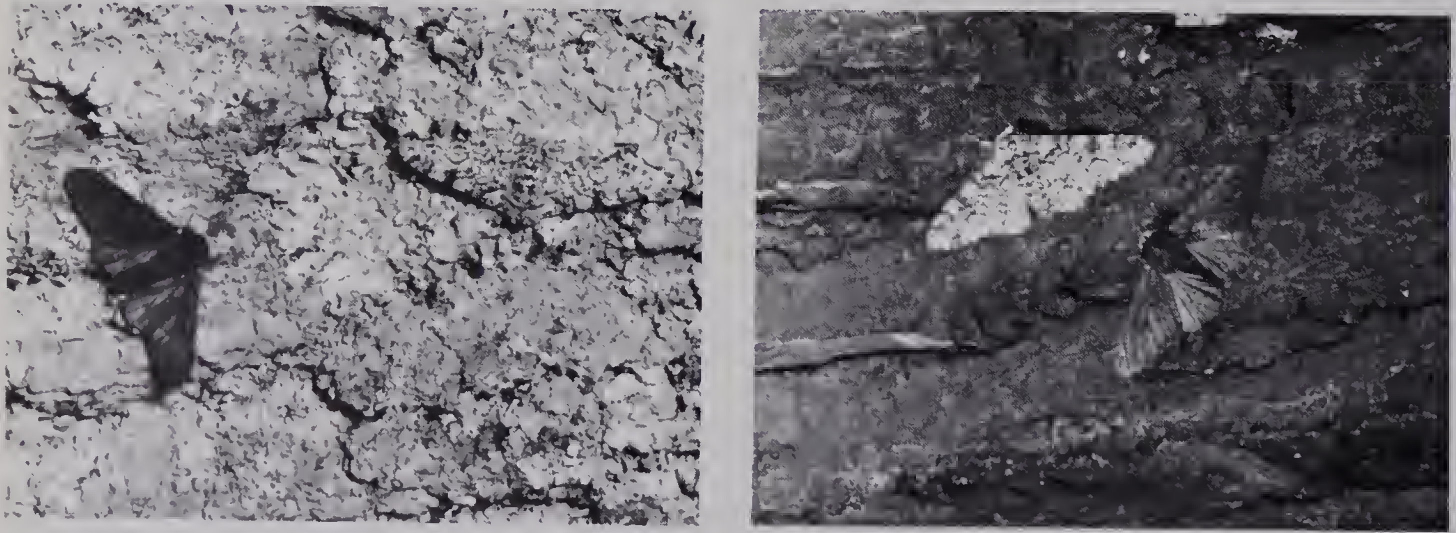
This change in the peppered moth population interested Professor Kettlewell, who continued the investigation. He selected two entirely different areas for study. One was in a bird reserve in Birmingham, an industrial city similar to Manchester. The other was a countryside near Dorset, an area where there was no soot on the trees.

In the bird reserve in Birmingham, Kettlewell released 477 black moths and 137 light moths. As he watched through the day, birds fed on the moths as they rested on tree trunks. That night he recovered most of the remaining moths by attracting them to a light. Altogether he recaptured 40 percent of the black moths but only 19 percent of the light moths.

In the countryside near Dorset he released 473 black moths and 496 light moths. Again the birds destroyed large numbers as they rested on trees of the region. Only 6 percent of the black moths were recaptured while 12.5 percent of the light moths survived.

Thus, we have an interesting demonstration of a principle biologists now call ***industrial melanism*** (*mel*-a-niz-m). A mutation, a resulting adaptation to a changed environment, and a predator combined to change an entire population of moths in 50 years. Industrial melanism is a demonstration of the importance of natural selection in the process of evolution.

Isolation as a factor in evolution. Two squirrel populations in the region of the Grand Canyon of the Colorado River illustrate the effect of ***isolation*** on the evolution of different forms. On the north rim of the Grand Canyon, we find the Kaibab squirrel, with long ears, white tail, and dark underparts. On the south rim is a similar animal, the Abert squirrel, with long ears but a gray tail and light underparts. Biologists consider these squirrels to be different species. Why have they developed separate characteristics when the two populations are so near? Between the two rims of the canyon is a fast-flowing river. In the depths of the canyon the temperature may reach 120° F. These factors have acted as barriers to the two groups of squirrels, preventing them from crossing the canyon and interbreeding. Over a period of thousands of years, the two populations have gradually become different from each other, although they probably started out as the same species. In other words, the



13-7 Left: a black peppered moth and a light peppered moth against a light surface. Right: the two phases against a dark surface. These illustrate the principle of industrial melanism. (Michael Tweedie from Photo Researchers, Inc.)

gene pools of the two groups were separated, so that as mutations occurred in each group, the variations between the two became more pronounced, until they could be considered two species.

A mountain range, a dry plain, a desert, or an ocean may act as a physical ***barrier*** preventing plants or animals from interbreeding. The populations of islands give striking examples of isolation. With an ocean as a barrier there is little or no opportunity for interbreeding with plants and animals on the mainland. This accounts for the development of totally different populations in the two areas.

Physical barriers are not the only causes for isolation of a species population, however. Any factor that prevents interbreeding may cause isolation. The sockeye salmon of the Fraser River is a good example. This great Canadian river has long been the ancestral spawning area of this salmon. A sockeye salmon hatches far up the river in shallow, cold water. Gradually it works its way downstream, finally arriving at the mouth of the river, where it disappears into the vast Pacific Ocean. Here it lives three or four years until maturity when a reproductive instinct urges it back to the mouth of the Fraser. Fighting the currents and leaping waterfalls, the salmon finally reaches its ancestral home — perhaps the very pool in which it hatched. Here it reproduces and dies. In the Pacific Ocean the sockeye mingles with other species of salmon. However, it never interbreeds with other species — only with other sockeyes and always in the Fraser River. Thus the sockeye salmon has remained an isolated breeding population. As might be expected, this has resulted in differences between the sockeye salmon and the salmon that breed in other streams.

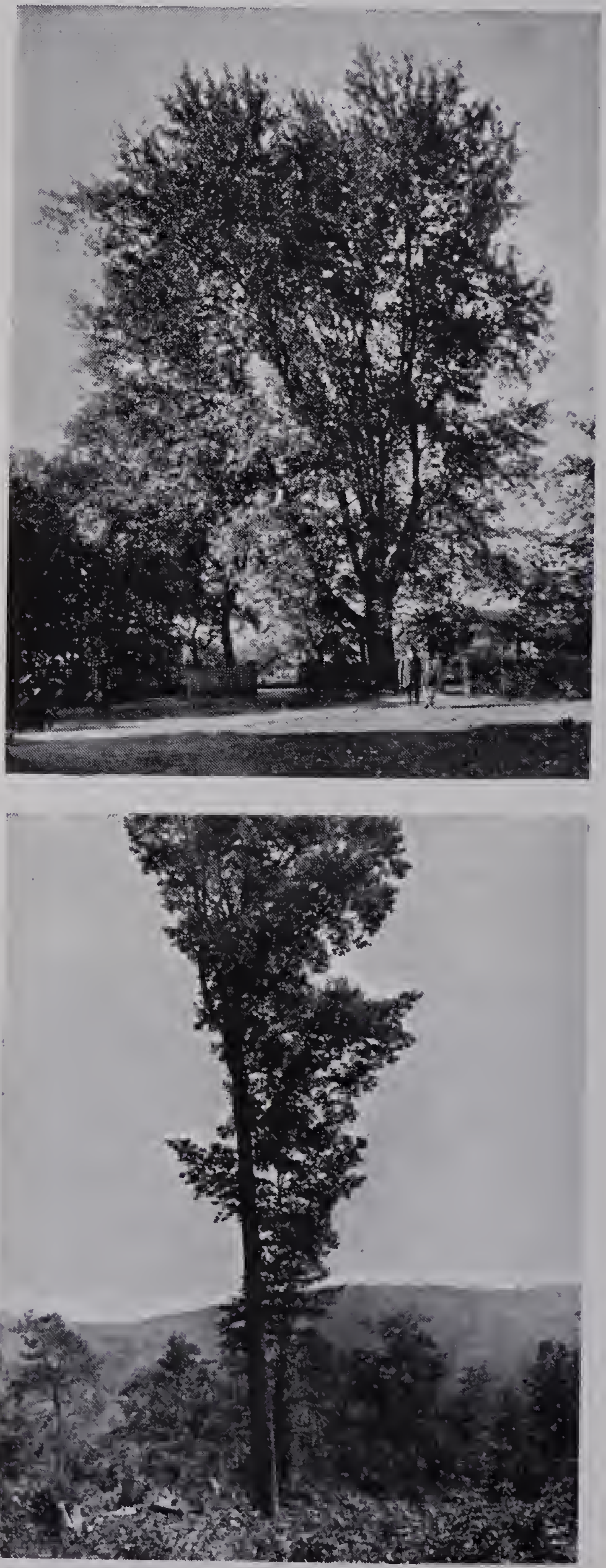
Other barriers to interbreeding include such factors as variation in the mating time of two populations, structural differences that prevent mating, and differences in mating habits. Sometimes interbreeding between two populations does occur but the resulting hybrids are sterile.

The development of species. A ***species*** is an individual kind of organism, distinct from all other organisms and capable of interbreeding with others of its

13-8 The Kaibab squirrel (top) occurs on the north rim of the Grand Canyon while the Abert squirrel exists on the south rim. The evolution of these two species has been affected by the barrier of the canyon. (Top: Union Pacific Railroad; bottom: Stophlet from National Audubon Society) kind. All members of a species have certain genetic likenesses. They have the same number of chromosomes and the same arrangement of genes on the chromosomes. The development of a species is a process called ***speciation*** (spee-shee-*ay*-shun). All through the ages species have been disappearing and new species have been developing. New species are being formed today, just as they have in past ages.

The mechanisms of variation, migration, or environmental change, selection, and isolation that we have been discussing result in speciation. To review how speciation may occur, let us condense the changes of perhaps thousands of years into a few sentences. Organism A is a member of a species population adapted to certain environmental conditions. However, the environment is such that migration can occur. Now we will assume that a mutation occurs in a member of the species population A. As the mutant gene increases in frequency in the population, certain organisms express the trait. We will designate these variations as AB. As both A and AB organisms migrate, they occupy a new and different environment. A is not entirely suited to the new conditions and may perish. However, the variation in AB is a favorable adaptation and it survives. Additional mutations occur. Those that are favorable to the new environment are preserved in offspring. Finally, a new species that we will designate as B is produced. Variation and selection have separated A and B to the extent that they can no longer interbreed.

Speciation in maples. Maples are found in many environments of North America. Several kinds have been introduced from Europe and Asia and thrive in our yards and parks and along city streets. Altogether 60 or 70 maple species are distributed through the Northern Hemi-



13-9 *Acer saccharinum,* the silver maple, is shown here at the top, while *Acer rubrum,* the red maple, is pictured at the bottom. Account for the differences in speciation in this genus. (U. S. Forest Service) sphere. Are all of these maples descendants of the same ancestral stock that lived many ages ago? Similarities in all of these maple species would indicate that they are. How, then, did they become so different?

Suppose that some time in the past a variation occurred in a maple that adapted it for life in wetter surroundings than maples had usually occupied. This might have been a difference in root structure. This new variety flourished in wet environments. Other variations resulted in further adaptations to wet surroundings. Finally a new maple species evolved. We call it the silver maple (*Acer saccharinum*). Today the silver maple is found throughout the eastern part of the United States. It towers to a height of 60 to 80 feet in bottomlands, swamps, stream borders, and river floodplains (lowlands that flood seasonally). While it lives best in lowlands, it may also tolerate much drier situations and, for this reason, is widely planted as a fast-growing shade tree. Perhaps you know it as the soft maple. It grows in shade in wet surroundings but requires more light in drier situations. Foresters are familiar with a variation of the silver maple that has deeply cut leaves. The cut-leaf maple grows more slowly and seldom reaches the size of a silver maple. Can you think of a reason why? Perhaps the cut-leaf maple is a new species in the making.

Maples in various forms occupy a wide range of environments in North America. The sugar maple and black maple thrive in the forests of eastern United States, while the moosewood maple mingles with the pines and hemlock of the northern forest. The striped maple prefers the elevations of eastern mountain ranges. The bigleaf maple is limited to a narrow belt in the Pacific coastal area from Alaska to California, where it lives in moist situations in foothills and low mountains.

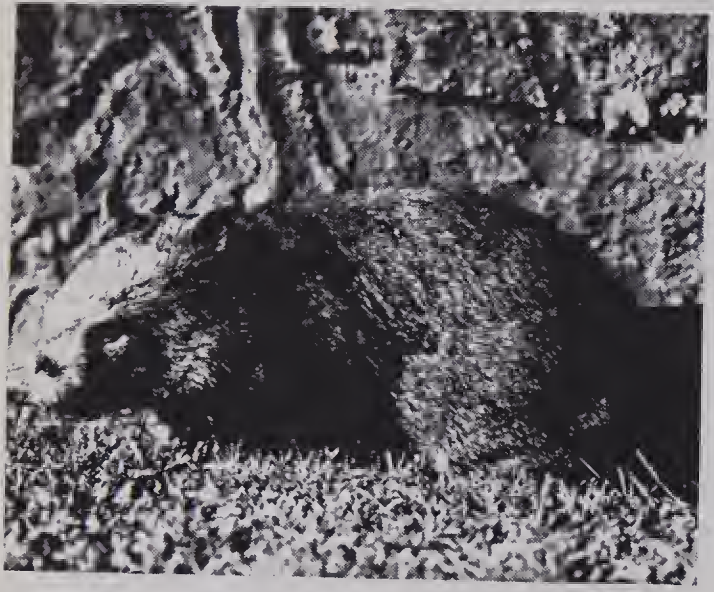
While all of the maple species have distinguishing characteristics, they have certain characteristics common to all maples. All maples in the world produce double-winged fruits known as samaras. The arrangement of buds on the stem is opposite in all maples. Their leaves tend to have a distinctive vein pattern. We refer to these similarities as ***genus*** characteristics. They represent a stable gene pool which has not changed as maples have evolved during speciation. Characteristics such as these, in addition to indicating evolutionary patterns, are important considerations in classification, a topic we shall discuss in Chapter 14.

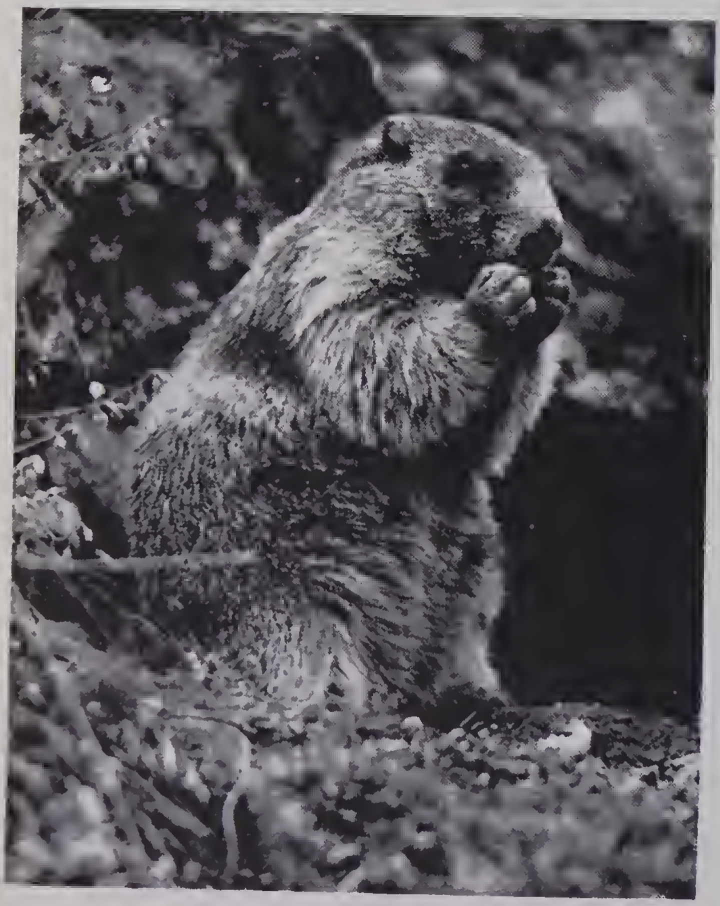
Adaptive radiation. The evolutionary pattern we have discussed in speciation is called ***adaptive radiation.*** It consists of a branching out of a population through variation and adaptation to occupy many environments. Speciation is evolution on a small scale. Often differences between species are slight. However, at some time much greater changes must have occurred and organisms must have branched out in a totally different direction.

Early in the Cenozoic Era, approximately 60 million years ago, primitive mammals were replacing the reptiles of earlier times. From these early mammals, three distinct lines arose by adaptive radiation. These were the egg-laying mammals, pouched mammals, and placental mammals. At one time, pouched mammals, or marsupials, were prominent in the animal population of the earth. In your study of mammals in Chapter 38, you will discover why the biologist considers marsupials more primitive and less favorably adapted to a land environment than the more recent placental mammals. Most of the mammals such as the dog, cat, horse and others with which you are familiar belong to this latter group.

For several million years placental mammals have been replacing the marsupials on most of the continents. Marsupials could not maintain their numbers against placental predatory mammals, such as the fox, wolf, lion, tiger, and leopard. But sometime many million years ago, Australia became isolated as an island continent. Marsupials dominated the mammal population and placental mammals never arrived to challenge them. As a result marsupials in Australia underwent the same adaptive radiation that was occurring among the placental mammals of other continents. The result was wide variation in form and in ecological relations.

When you think of Australia, perhaps you also think of a kangaroo. What would you compare with a kangaroo among North American mammals? If you look at the head of the kangaroo and watch it graze, you would probably say deer or antelope. But a biologist would say the opossum, for here is a true relationship, because the opossum is a marsupial. A small bear-like marsupial lives in the eucalyptus groves of Australia. We call it a Koala bear. But is it a bear because it resembles one? The same adaptive radiation that produced the bear in other parts of the world may have produced the Koala in Australia. The same resemblance of marsupials and placental counterparts is to be found in the marsupial moles and true moles, marsupial Tasmanian wolf and wolves of other continents, the wombat and the woodchuck and the phalanger and the squirrels. When you compare the kangaroo, Koala bear, marsupial mole, Tasmanian wolf, wombat, and phalanger, you see the great diversity among marsupials resulting from adaptive radiation.





13-10 The wombat (top) is a beaver-like burrowing marsupial whose geographical habitat is the hilly country of eastern Australia. The groundhog (bottom) is a placental rodent occurring in North America. Note the similarity of form and function in spite of differences in classification. (Top: Australian News and Information Bureau; bottom: Annan Photo Features)

13-11 The sea lion above and the whale below show similar adaptations because both inhabit the same general environment, even though they belong to different orders of mammals. (Top: Marineland of the Pacific; bottom: N. Y. Zoological Society)

On the other hand, compare the deer, bear, mole, wolf, woodchuck, and squirrel, and you are impressed with the results of adaptive radiation in placental mammals.

Convergent evolution. Now let us consider a condition nearly the reverse of adaptive radiation. In this case, the environment is the same and organisms of entirely different origin evolve in a manner that results in certain similarities. We speak of this kind of change as ***convergent evolution.*** Consider the marsupials and placental mammals we used as examples of adaptive radiation; when we compare all members of either group with each other, we can illustrate convergent evolution by considering the same organisms from a different point of view. Consider the marsupial mole and the true mole, a placental mammal. Adaptation to similar surroundings and mode of life has made these animals similar, even though they have only a distant biological relationship. The whale and the seal are other good examples of convergent evolution. Both live in the open sea. They have flippers for locomotion. Both, while lung breathers, can hold their breath and submerge temporarily. A thick layer of fat beneath the skin protects both animals from loss of body heat in the cold ocean water. The living world is full of examples of convergent evolution in which unrelated organisms develop similar structures as adaptations to an environment that they share.

IN CONCLUSION

For many millions of years organisms of the earth have been undergoing change. With change may come improvement as the process of natural selection weeds out the undesirables and poorly adjusted organisms. Thus life forms evolve to occupy their respective places in the face of change.

Modern genetics has placed the mechanisms of evolution in a more logical, reasonable, and comprehensible light. With gene and chromosomal mutations come variations — both good and bad. Natural selection operates to sort the good from the bad. Change meets change. This is the story of organic evolution.

The evolutionary process has resulted in the great diversity of life on earth today. In the next chapter we shall discuss the biologist's methods of naming and classifying these numerous and varied living things.

BIOLOGICALLY SPEAKING

adaptive radiation
barrier
convergent evolution
corridor
evolution
geological era
geological period
geologist
homologous structures
industrial melanism
isolation
migration
natural selection
speciation
species
survival of the fittest
sweepstakes dispersal
vestigial organ

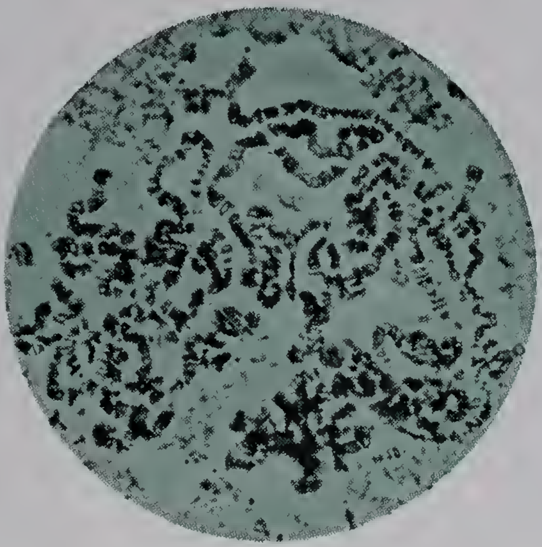
QUESTIONS FOR REVIEW

1. List several biological evidences of change.
2. Describe the three theories in Lamarck's explanation of evolution.
3. What concepts are included in Darwin's theory of evolution?
4. What significant contribution did De Vries make to evolution?
5. Explain how gene mutations cause variations in organisms.
6. Explain why gene mutations seldom appear in the individual in which they occur.
7. List several causes of chromosomal mutations.
8. Explain how recombination operates as a source of variation.
9. How are mutant traits expressed through recombination?
10. List two direct evolutionary results of migration.
11. Why are corridors important in migration?
12. Explain how a black moth appeared in the peppered moth population in Manchester, England, in 1845.
13. Describe several barriers that may isolate an environment.
14. How may isolation of a population lead to speciation?
15. Generally, what occurs in adaptive radiation?
16. Give an example of convergent evolution in organisms you have seen.

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the importance of structural, physiological, and biochemical similarities in determining paths of evolution.
2. Explain the development of the long neck of the giraffe according to Lamarck, according to Darwin, and according to modern theory.
3. Discuss the genetic significance of the results of studies of the peppered moth in England.
4. Discuss mutations, recombination, interbreeding, and selection as mechanisms in evolution.
5. Compare adaptive radiation and convergent evolution as factors in evolution.

CHAPTER 14



THE DIVERSITY OF LIFE

The science of classification. In our study of evolution in the previous chapter, we discussed the various species of maples and the way in which they have probably evolved by adaptive radiation. The science of genetics has given us a foundation for understanding how such evolution occurs. A study of evolution has in turn enabled us to find natural relationships between living things. Early biologists, however, attempted to group and name living things without the knowledge of genetics and evolution that we have now. The classification of organisms, a branch of biology known today as ***taxonomy,*** has been of concern to biologists since ancient times.

Aristotle, the Greek philosopher, probably devised the first classification system. He divided plants into three groups: the herbs, with soft stems; the shrubs, with several woody stems; and the trees, with a single woody trunk. He divided animals into three groups on the basis of where they lived: the water dwellers, the land dwellers, and the air dwellers.

In the 18th century the great Swedish botanist Carolus Linnaeus (li-*nee*-us) devised a classification system that in many respects is still in use today, in spite of the fact that he had no knowledge of genetics or evolution. Linnaeus believed that the main aim of science was to find order in nature. He recognized the species as the basic natural grouping, and thought that species were unchanging. He sought to group all the known plants and animals into a fixed number of species, according to their structural similarities. He disregarded any organism that did not fit into his species categories. Perhaps if Linnaeus, like Darwin, had recognized that these organisms that did not fit into his categories were in the process of change, the theory of evolution would have been developed much earlier.

Linnaeus discarded the common names of plants and gave each one a scientific name made up of Latin words. None of these names was taken from his own language or from any other modern language. There are several reasons why Linnaeus chose Latin as the language of classification. First, since it was no longer in use, it was unchanging. Furthermore, many modern languages contain words taken directly from this ancient language. Latin was understood by scientists of all countries. Also, many descriptive Latin words are ideally suited for identifying the characteristics of an organism.

Linnaeus published his list of plant names in 1753 and his list of animal names in 1758. Each scientific name had at least two parts. Usually the name referred either to some charac-

14-1 The Latin name for the black bear (left) is *Ursus americanus*, while that for the grizzly is *Ursus horribilis*. (Left: Annan Photo Features; right: Harrison from Monkmeyer)

teristic of the organism or to the person who named it. Many of his names are in use today and can be recognized by the *L.* that appears at the end of them.

How scientific names are written. Linnaeus' system of giving each organism a scientific name of two or more parts is called ***binomial nomenclature***, or "two-word naming." The first name refers to the genus and always begins with a capital letter. The species name follows and usually begins with a small letter. The genus name is usually a noun and the species name an adjective. The placing of the noun before the adjective is regular Latin order. We use a similar system in official lists of names where John Smith appears as Smith, John. In addition, scientific names are usually printed in italic type or underlined.

The species is still the basic group used in classifying organisms. The members of a species are similar in structural characteristics, and they can mate and produce fertile offspring. Thus, all domestic cats are of one species although they may differ in size, color, and shape. All human beings belong to the same species.

Closely related species are placed together in the larger group called the genus. For example, *Pinus* is the name of the genus into which all pine trees are grouped. There are many different species of pine trees. *Pinus resinosa*, for example, is the red pine, and *Pinus strobus* is the white pine.

In devising his standardized naming system, Linnaeus enabled biologists to avoid the confusion and the misleading nature of common names. The mountain lion, for example, is also known as the puma, or cougar. It is called the panther, silver lion, American lion, mountain demon, mountain screamer, king cat, sneak cat, varmint, brown tiger, red tiger, and deer killer. Under the Linnaean system, however, all scientists easily identify this animal as *Felis concolor*. The common house cat is *Felis domestica*, as it belongs to the same genus as the mountain lion but is of a different species. *Felis onca* is the jaguar, while you will recognize *Felis leo* as the real African lion.

Since organisms are classified according to structural similarity under the Linnaean system, scientific names are not as misleading as most common names. For example, what is a fish? If you think of a fish as an animal with a backbone, scales, fins, and gills, you are using the name correctly and scientifically. The perch, cod, halibut, bass, and salmon are fishes. But what about the silverfish? It is an insect. We call clams and oysters shellfish. And we call other animals in no way resembling a true fish crayfish, jellyfish, and starfish. We shall use these names, even in the study of biology, because they are familiar. But when you learn more about these animals you will understand why the term "fish" is misleading in referring to them.

The basis of scientific classification. From the time of Linnaeus until recently, most scientific classification has been based on *structural similarity*. For example, the cow is structurally similar to the bison and the deer. All are cud-chewing mammals with large molar teeth for grinding plant foods and two-toed hoofs adapted for weight bearing and running over hard ground.

On this basis biologists have classified organisms into groups, starting with very large divisions and continuing with smaller groups to a single species. The smaller the classification group, the more similar its members are.

14-2 Although the common names of these animals are starfish, crayfish, and jellyfish, not one of them is a true fish. They are not even structurally like a fish, nor are they closely related to one another. (Walter Dawn)

A MODERN CLASSIFICATION OF ORGANISMS

Kingdom – Protista

Organisms having a simple structure; many unicellular, others colonial or multicellular, but lacking in specialized tissue; both heterotrophic and autotrophic; neither distinctly plant nor distinctly animal.

PHYLUM	ORGANISMS
Schizomycophyta	Bacteria
Cyanophyta	Blue-green algae
Chlorophyta	Green algae
Chrysophyta	Golden-brown algae, or diatoms
Pyrrophyta	Dinoflagellates and cryptomonads
Phaeophyta	Brown algae
Rhodophyta	Red algae
Mycophyta	Fungi
Myxomycophyta	Slime molds
Sarcodina	Amoeboid organisms
Mastigophora	Flagellates
Ciliophora	Ciliates
Sporozoa	*Plasmodium*

Kingdom – Plantae

Multicellular plants having tissues and organs; cell walls containing cellulose; chlorophyll *a* and *b* present and localized in chloroplasts; food stored as starch; sex organs multicellular; autotrophic.

PHYLUM	SUBPHYLUM	CLASS	ORGANISMS
Bryophyta			Liverworts, hornworts, and mosses
Tracheophyta			Vascular plants
	Psilopsida		*Psilotum, Tmesipteris* (only living genera)
	Lycopsida		Club mosses
	Sphenopsida		Horsetails (*Equisetum*), and calamites
	Pteropsida		
		Filicineae	Ferns
		Gymnospermae	Seed ferns, cycads, *Ginkgo*, and conifers
		Angiospermae	Flowering plants

Kingdom – Animalia

Multicellular animals having tissues and, in many, organs and organ systems; pass through embryonic or larval stages in development; heterotrophic.

PHYLUM	SUBPHYLUM	ORGANISMS
Porifera		Sponges
Coelenterata		Coelenterates
Ctenophora		Comb jellies
Platyhelminthes		Flatworms
Nemertea		Ribbon worms
Nematoda		Roundworms
Nematomorpha		Horsehair worms
Acanthocephala		Spiny-headed worms
Trochelminthes		Rotifers
Bryozoa		Bryozoans, sea mosses
Brachiopoda		Brachiopods, or lampshells
Phoronidea		Phoronis
Chaetognatha		Arrow worms
Mollusca		Mollusks
Annelida		Annelids, segmented worms
Arthropoda		Arthropods
Echinodermata		Echinoderms
Chordata		Chordates
	Hemichordata	Tongue worms, acorn worms
	Tunicata	Tunicates
	Cephalochordata	Lancelets
	Vertebrata	Vertebrates

THE CLASSIFICATION OF SIX DIFFERENT ORGANISMS

	Man	*Grasshopper*	*Dandelion*	*White pine*	*Ameba*	*Typhoid bacterium*
Kingdom	Animalia	Animalia	Plantae	Plantae	Protista	Protista
Phylum	Chordata	Arthropoda	Tracheophyta	Tracheophyta	Sarcodina	Schizomycophyta
Class	Mammalia	Insecta	Angiospermae	Gymnospermae	Rhizopoda	Schizomycetes
Order	Primates	Orthoptera	Campanulales	Coniferales	Amoebida	Eubacteriales
Family	Hominidae	Acridiidae	Compositae	Pinaceae	Amoebidae	Bacteriaceae
Genus	*Homo*	*Schistocerca*	*Taraxacum*	*Pinus*	*Amoeba*	*Eberthella*
Species	*sapiens*	*americana*	*officinale*	*strobus*	*proteus*	*typhosa*

Recently, however, biologists have considered other characteristics in classifying organisms. One is *cellular organization*, including nuclear structure, plastids, and other cell organelles. Another is *biochemical similarity*. For example, cells of closely related organisms may synthesize the same organic compounds. The most conclusive evidence of relationship between organisms, however, is in their *genetic makeup*, since all the above characteristics are determined by genes. If two animals have the same number of chromosomes, and the chromosomes of one animal are identical or very similar in structure to those of the other animal, you can be sure that the two animals are closely related.

Groupings in the Linnaean system. If you had a specimen of each of the more than one million kinds of plants and animals known to exist and started grouping them, where would you begin? Wouldn't it be best to divide them first into plants or animals? This is where the biologist begins his classification. He separates living things first into very large groups called ***kingdoms***. Next he divides each kingdom into smaller groups known as ***phyla***. Each phylum is in turn divided into ***classes***. A class contains many ***orders***. A division of an order is a ***family***. A family contains related genera, and a ***genus*** is composed of more than one ***species***. Sometimes individuals of a single species vary slightly, but not enough to be considered separate species. We refer to them as ***varieties***.

14-3 Similarity in structure and function does not necessarily indicate close biological relationship. These are all flying animals but the bat, the dragon fly, and the bird are not at all closely related. (Top: Davidson from National Audubon Society; middle and bottom: Annan Photo Features)

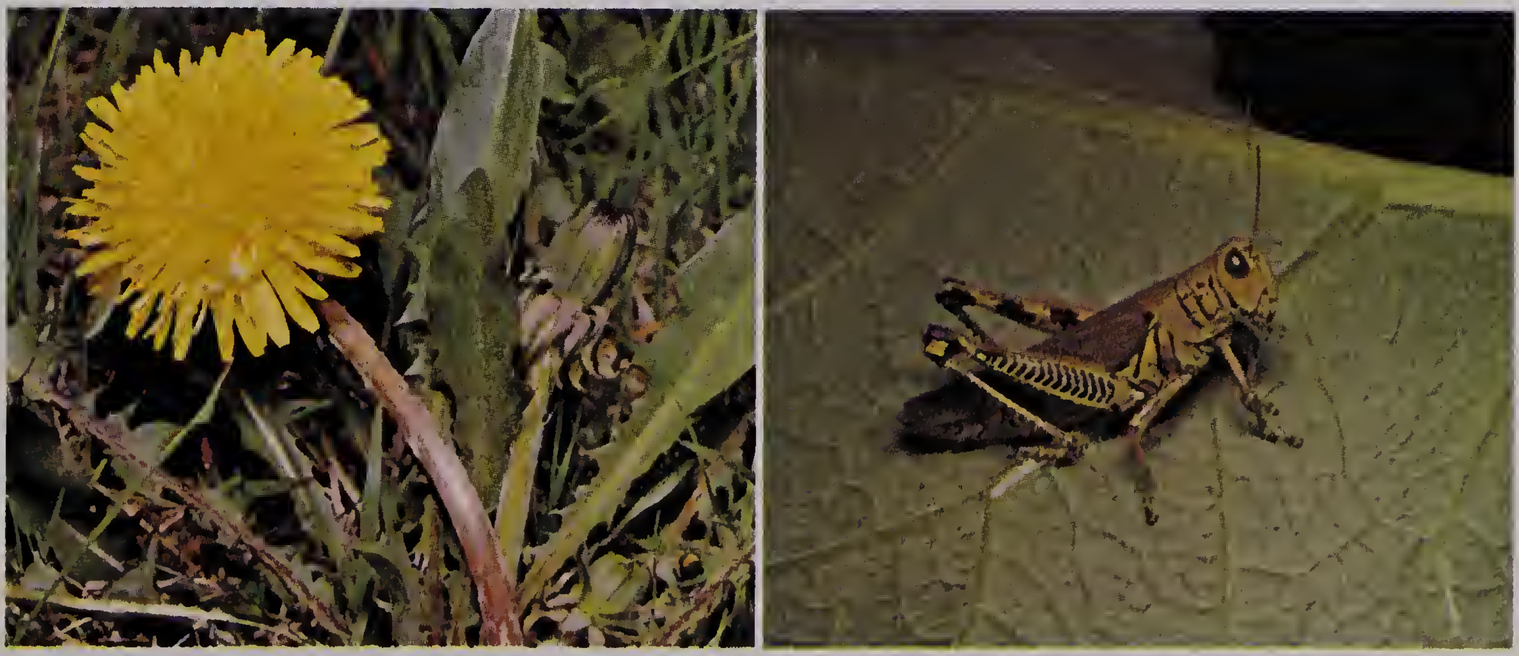
An organism considered a variety has a third part to its scientific name.

As an example of how organisms are classified into these groupings, let us use man. The kingdom Animalia includes all animals. The phylum Chordata includes all animals having backbones, with a few exceptions, which we shall discuss later. The class Mammalia includes all animals having mammary glands. The order Primates includes only a certain group of mammals that stand nearly erect. Monkeys, chimpanzees, and gorillas are primates. The family Hominidae (hoh-*mih*-nih-dee) separates early manlike forms from the other primates. The genus *Homo* includes all true men. The species *sapiens* (which means "wise") is the only surviving species of man on earth.

Some biologists further divide man into races, which are similar to varieties in other organisms. The classification of man and five other organisms may be found in the table on page 203, bottom.

Problems in classification. As you examine various biological references, you may wonder at the wide variation in the classification systems. How many kingdoms do we recognize today? How are the phyla of living things placed in these kingdoms, and on what basis are these distinctions made? As we attempt to classify the diverse forms of life, from the simplest bacteria and protozoans to seed plants and complex vertebrates, we must remember that any system of grouping is purely man-made. We divide living things into classification groups for our own convenience. In the evolution of life from simple to more complex forms, nature did not leave gaps for us to use in establishing classification groups. The question then is where do we draw the line in forming these groups. What is a plant? What is an animal? When is an organism neither plant nor animal?

These questions did not bother biologists much until recent years. They recognized only two kingdoms — plant and animal. The plant kingdom contained four great phyla, while the animal kingdom included 20 or more, depending on the system used. This traditional classification served very well for many years. Since it is still the basis for many of the books you will use as references, we have included the two-kingdom system in the Appendix.



14-4 Classify the dandelion and the grasshopper according to phylum. (Walter Dawn)

14-5 Here are four organisms: a date palm, a barberry sheep, a paramecium, and a euglena. It is simple to classify the first two as either animal or plant, but quite a different story to classify microscopic organisms into their respective groupings. (Walter Dawn)

In the past few decades a great amount of research has focused on simpler forms of life. Are these organisms plants? Are they animals? Actually they are neither. They are more closely related to one another than to organisms we consider definitely plant or animal. Traditional classification has provided no real place for these "in-between" organisms. Thus biologists have recognized the need for classifying them in a different way. Some systems place the bacteria and the blue-green algae in a kingdom called the ***Monera*** (moh-*ner*-a). These organisms have one striking characteristic in common — they lack an organized nucleus. Some biologists even place the viruses in this kingdom, while others present valid arguments claiming that a virus isn't even a living organism.

A second kingdom, universally recognized in more recent classifications, is known as the kingdom ***Protista*** (proh-*tis*-ta). There seems to be little doubt that such a kingdom should be established, but there is disagreement as to what phyla should be included. If the kingdom Monera is not recognized, then bacteria should certainly be placed among the protists. Protozoans are also placed in this kingdom. The real problem arises in what to do with the algae and fungi. The simpler members of these groups seem logically to be protists. But these same groups include organisms such as the kelps and mushrooms that are more like true plants. On the basis of size and limited cell specialization, however, it may be more reasonable to place all the various algae and fungi in the same kingdom. For this reason, we shall use in this book a three-kingdom classification system in which the bacteria, fungi, algae, and protozoans constitute the kingdom Protista (see table on page 202). Remember that this is not the only system, nor is it by any means perfect. We cannot say that one system is right and another wrong. We are simply choosing one system as a convenience in organizing our study of the world of life.

The definition of a species. An even greater problem in classification is an exact definition of a species. We have defined a species as an individual or distinct kind of living thing. But this is only a working definition because the biologist cannot always be sure when to classify two similar plants or animals as separate species and when to classify one as a variety of the other. Remember, for example, our discussion of speciation in maples in Chapter 13. It is difficult to determine exactly when to name as two different species two types of maples that are evolving by adaptive radiation. Biologists usually agree, however, on the following three general characteristics of species:

1. A species is structurally different from all other organisms except for sexual differences (male and female), and slight variations resulting from environmental influences.
2. Members of a species can interbreed and produce offspring that are capable of further reproduction. In other words, all members of a species have the same genetic makeup.
3. Members of a species have come from common ancestors and will continue their species characteristics.

IN CONCLUSION

Although Carolus Linnaeus did not recognize the changing nature of species, he may be considered one of the great biologists for his contribution in bringing order to the great diversity of life. Since the 18th century biologists throughout the world have used his system of binomial nomenclature, and his system of groupings from kingdom to species.

While classification is a convenience, it is important to remember that it is of man's devising, and that in the future we may learn new ways of grouping organisms that will more accurately reflect their evolutionary relationships.

We are now ready to begin our study of groups of living things. We shall begin with the viruses, which seem to be on the borderline between life and nonlife.

BIOLOGICALLY SPEAKING

binomial nomenclature
class
family
genus
kingdom
order
phylum
species
taxonomy
variety

QUESTIONS FOR REVIEW

1. What is the science of classification called?
2. On what bases did Aristotle attempt to classify plants and animals?
3. Why is Latin an ideal language for biological classification?
4. Explain the binomial system of naming organisms.
5. Discuss ways in which common names are both confusing and misleading.
6. On what characteristics of an organism is its classification based?
7. Name the classification groups from the largest to the smallest.
8. Discuss the problems biologists have encountered in trying to classify organisms into kingdoms.
9. How do most biologists define a species?

APPLYING PRINCIPLES AND CONCEPTS

1. Give examples to show that size, habitat, and diet similarities show no true animal relationships that could be considered in classification.
2. Make a list of plants and animals of your region that have more than one common name.
3. The fox, wolf, and coyote are different species of the dog family. On the other hand, the cocker spaniel, collie, and poodle are breeds of the domestic dog. Distinguish between a species and a breed, or variety.
4. How can the principles of scientific classification be made useful in areas outside biological study?

RELATED READING

Books

Altenburg, Edgar. *Genetics.* Holt, Rinehart and Winston, Inc., New York. 1957.

Asimov, Isaac. *The Genetic Code.* Orion Press, New York. 1962

Auerbach, Charlotte. *The Science of Genetics.* Harper and Row, New York. 1961

Bates, Marston and Humphrey, Philip S., Editors. *The Darwin Reader.* Charles Scribner's Sons, New York. 1957

Beaty, John Y. *Luther Burbank: Plant Magician.* Julian Messner, Inc., New York. 1943

Bonner, David. *Heredity.* Prentice-Hall, Inc., Englewood Cliffs, N. J. 1961

Cain, A. J. *Animal Species and Their*

Evolution. Harper and Row, New York. 1960

Clare, June. *The Stuff of Life*. Progress of Science Series, Roy Publishers, New York. 1964.

Darwin, Charles. *Evolution and Natural Selection*. Beacon Publishers, Boston. 1959

Darwin, Charles. *Origin of the Species by Means of Natural Selection*. Collier Books, New York. 1962

Darwin, Charles. *Problem of World Population*. Cambridge University Press, New York. 1958

Dickinson, Alice. *Charles Darwin and Natural Selection*. Franklin Watts, Inc., New York. 1964

Dobzhansky, Theodosius. *Genetics and the Origin of Species*, 3rd Rev. Ed. Columbia University Press, New York. 1951

Dowdeswell, W. H. *The Mechanism of Evolution*. Harper Torchbooks, Harper and Row, New York. 1960

Fast, Julius. *Blueprint for Life: The Story of Modern Genetics*. St. Martin's Press, Inc., New York. 1964

Gardner, Eldon. *Principles of Genetics*, 2nd Rev. Ed. John Wiley and Sons, Inc., New York. 1964

Goldschmidt, Richard B. *Understanding Heredity*. John Wiley and Sons, Inc., New York. 1952

Goldstein, Philip. *Genetics is Easy*, 2nd Ed. Viking Press, Inc., New York. 1961

Huxley, Julian. *Evolution in Action*. Mentor Books, New York. 1957 (Also Harper and Row, New York. 1953)

James, John. *Create New Flowers and Plants*. Doubleday and Co., Garden City, N. Y. 1964

King, Robert C. *Genetics*. Oxford University Press, New York. 1962

Lerner, Marguerite R. *Who Do You Think You Are?* Prentice-Hall, Inc., Englewood Cliffs, N. J. 1964

Ludovici, L. *Links of Life: The Story of Heredity*. G. P. Putnam's Sons, New York. 1962

Montagu, Ashley. *Human Heredity*, 2nd Rev. Ed. World Publishing Co., Cleveland. 1964

Penrose, Lionel Sharples. *Outline of Human Genetics*, 2nd Ed. John Wiley and Sons, Inc., New York. 1963

Penrose, Lionel Sharples. *Recent Advances in Human Genetics*. Little Brown and Co., Boston. 1961

Randal, Judith. *All about Heredity*. Random House, Inc., New York. 1963

Roberts, Elmer. *Heredity: What and How We Inherit*. Bookmailer, Inc., New York. 1959

Scheinfeld, Amram. *The Human Heredity Handbook*. J. B. Lippincott Co., Philadelphia. 1956

Scheinfeld, Amram. *The New You and Heredity*. J. B. Lippincott Co., Philadelphia. 1951

Scheinfeld, Amram. *Why You Are You*. Abelard-Schuman Ltd., New York. 1958

Sheppard, P. M. *Natural Selection and Heredity*. Harper and Row, Philadelphia. 1960

Snyder, Laurence H. and David, Paul R. *The Principles of Heredity*, 5th Ed. D. C. Heath and Co., Boston. 1957

Sutton, Harry E. *Genes, Enzymes and Inherited Diseases*. Holt, Rinehart and Winston, Inc., New York. 1961

Webb, Robert. *Gregor Mendel and Heredity*. Franklin Watts, Inc., New York. 1963

Winchester, Albert M. *Genetics: A*

Survey of Principles of Heredity. Houghton, Mifflin Co., Boston. 1958

Winchester, Albert M. *Heredity and Your Life: An Account by Everyday Human Inheritance.* Vantage Press, New York. 1956

Winters, Laurence M. *Animal Breeding,* 5th Ed. John Wiley and Sons, Inc., New York. 1954

Articles

Bearn, A. G. and German, J. L., III. "Chromosomes and Disease," *Scientific American.* November, 1961

Beer, Wolfgang and Ulrich Clever. "Chromosome Puffs." *Scientific American.* April, 1964

Crick, F. H. C. "The Structure of the Heredity Material." *Scientific American.* October, 1954

Crow, James F. "Ionizing Radiation and Evolution." *Scientific American.* September, 1959

Deevey, Edward S. "The Human Population." *Scientific American.* September, 1960.

Dobzhansky, Theodosius. "The Genetic Basis of Evolution." *Scientific American.* January, 1950

Hotchkiss, Rollin D. and Esther Weiss. "Transformed Bacteria." *Scientific American.* November, 1956

Hurwitz, Jerard and J. J. Furth. "Messenger RNA." *Scientific American.* February, 1962.

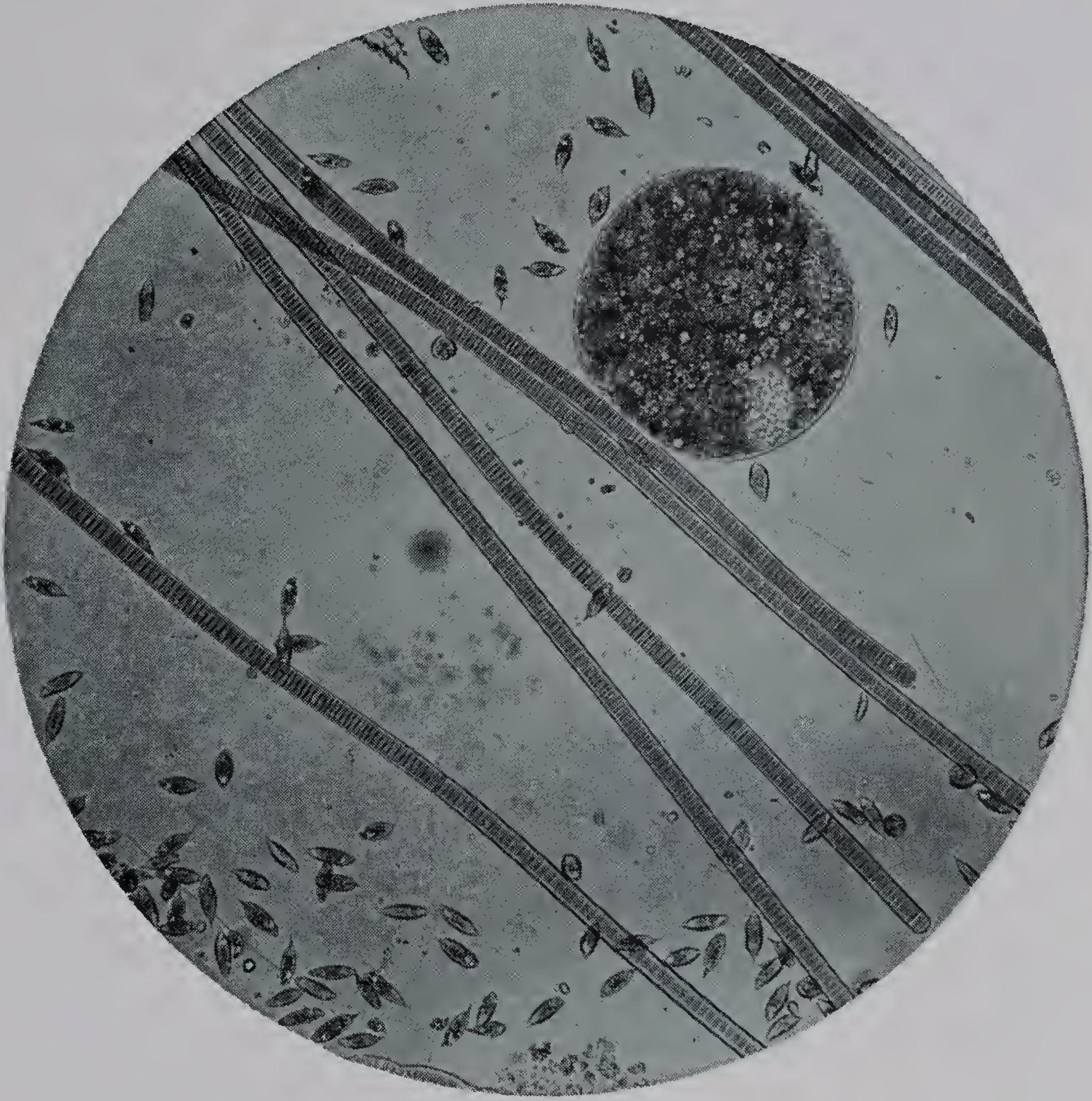
Lack, David. "Darwin's Finches." *Scientific American.* April, 1953

Mangelsdorf, Paul C. "The Mystery of Corn." *Scientific American.* July, 1950

Nirenberg, Marshall W. "The Genetic Code." *Scientific American.* March, 1963

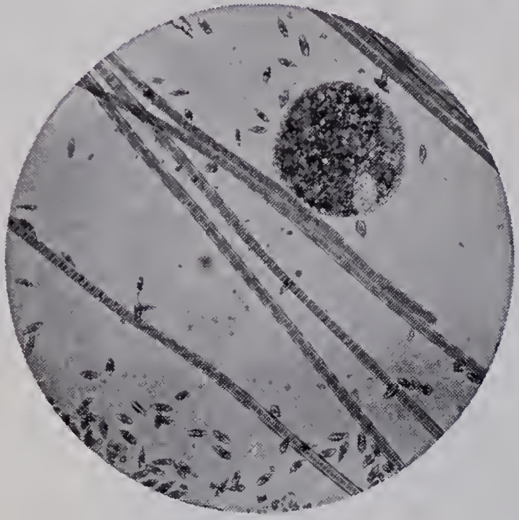
UNIT THREE

MICROBIOLOGY



Your study of microbiology will take you to the fringe of life, where organic molecules first exhibit properties which we associate with the living condition. In the composition of a virus, we find nuclear substances without a cellular organization. Continuing from this primitive state, we find cells of increasing complexity which constitute entire organisms. We cannot designate them as definitely plant or animal and, therefore, we refer to them as protists. In this vast assemblage of lowly organisms, we find cells which lead a solitary life, cells grouped in colonies, and organisms which approach the multicellular organization of higher forms of life.

CHAPTER 15



THE VIRUSES

Viruses – living or nonliving. In beginning our study of microbiology with the viruses, we are introducing one of the most recent and exciting areas of biology, the science of virology. We are also presenting an entirely new concept of the living and the nonliving, for a virus qualifies in both categories and seems to shuttle back and forth between the two.

Before biologists had explored viruses and understood their structure and activities, they had drawn a definite line between nonliving substances and living organisms. Then came our knowledge of viruses to upset what we had thought to be a clear-cut distinction. In a virus we find a particle definitely linked to biochemical processes in its organization and unlike any nonliving material, yet in itself not actually living. But in the presence of a living system within a cell, a virus seems to be very much alive. Could it be that a virus is alive at some times and not at others? Who can say, when no one has yet given an adequate definition of life?

Regardless of the classification of viruses as living or nonliving, however, it is appropriate to deal with them in a unit on microbiology. If they are nonliving, they are unique because their influence on cell activities is different from that of any other nonliving material. If they are living, they are certainly the most basic organisms, representing life at the molecular level.

What are viruses? At the mention of the word *virus,* you probably think of an agent of disease. In many respects you would be right. You are familiar with the polio virus and probably associate viruses with smallpox, chickenpox, influenza, rabies, and the common cold. These are but a few virus diseases. More than 300 different viruses are known to produce diseases in various organisms. Scientists, too, thought that all viruses were pathogenic agents until recent years. Would it surprise you to learn that many virus particles are apparently harmless and that few cells escape some kind of virus invasion?

Virus particles are noncellular, or perhaps we should say subcellular. That is, they are below the level of cellular organization. They have no nucleus, no cytoplasm, and no surrounding membrane. They are larger than molecules yet much smaller than the smallest cells. The name ***filterable virus*** refers to the fact that they pass through the extremely small pores of unglazed porcelain filters used in separating bacteria from fluids.

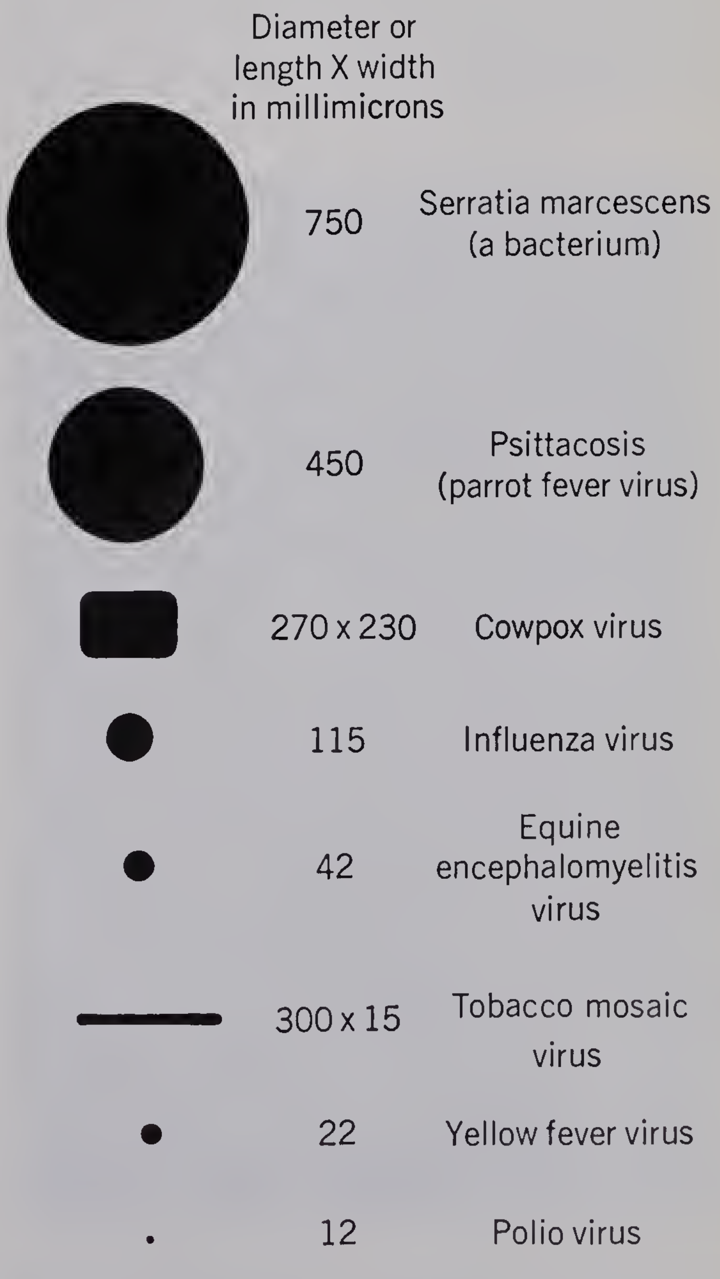
All but the largest virus particles are invisible under even the highest magnification of a light microscope. For this reason little could be determined about the structure of a virus until the invention of the electron microscope. With this instrument, even the smallest viruses have been photographed. We are now familiar with the form of various viruses as well as with the size of their particles.

Viruses tend to be one of four shapes. Some are in the form of slender, needlelike rods, while others are spherical or cubical or brick-shaped. Still others have an oval or many-sided head and a slender tail somewhat resembling a tadpole.

Viruses are measured in millimicrons, for which we used the abbreviation mμ. When you consider that one millimicron is 0.001 micron and that one micron is 0.001 millimeter, you can appreciate the extremely small size of virus particles. Figure 15–1 shows the average diameters of several viruses. The smallest bacteria, which would appear as tiny specks under the high power of your microscope, range from 500 to 750 millimicrons.

The discovery of viruses. Scientists worked with virus diseases long before a virus was known to exist. Dr. Edward Jenner performed the first vaccination against smallpox in 1796 when he transferred a virus-containing fluid from a cowpox sore on the hand of a dairymaid to a scratch on the arm of an eight-year-old boy. About a century later Louis Pasteur discovered that the rabies infection centered in the brain and spinal cord and successfully transmitted the disease to a laboratory animal by injecting infected brain and spinal cord substance. While both of these men made significant medical contributions that we shall discuss later, neither had any concept of a virus as an agent of infection. Other 19th and 20th century investigators working with virus diseases described virus-containing materials as contagious fluids, destructive chemical substances, and destructive enzymes.

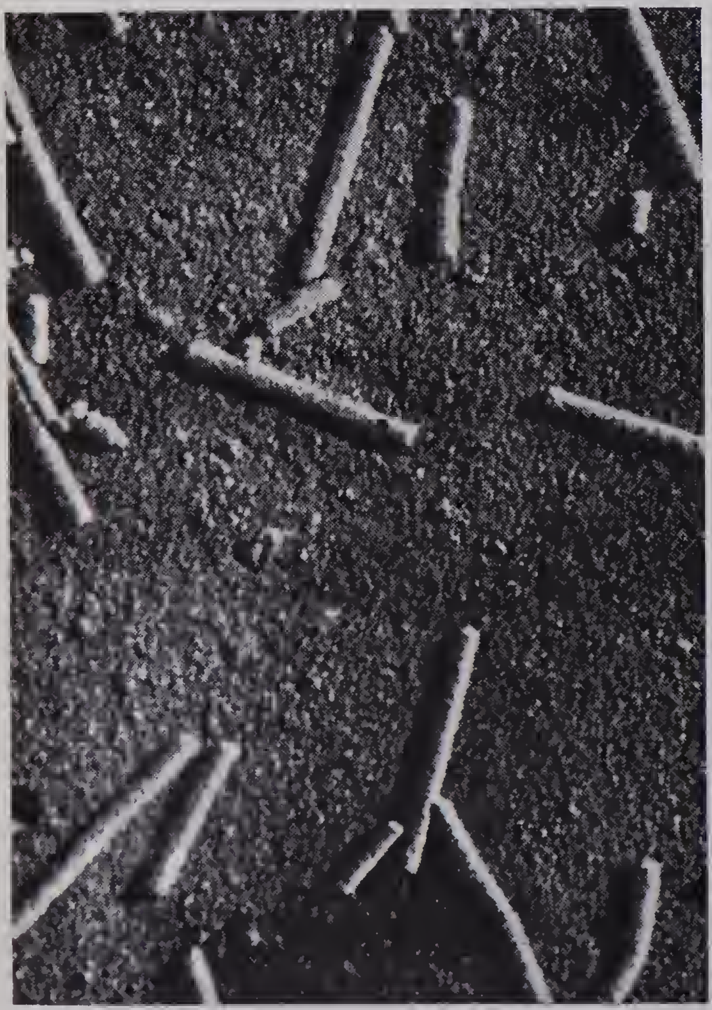
In 1935 Dr. Wendell Stanley made a significant discovery while working with a disease of tobacco plants at the Rockefeller Institute. The disease is a virus infection known as tobacco leaf mosaic, one of many similar plant infections. The name *mosaic* refers to a curious pattern of light green and yellow areas that appears in the leaves as tissues are destroyed by virus attack. As the disease progresses, the leaves become stunted and wrinkled. In the study of this disease Dr. Stanley extracted virus crystals from infected leaves and found that they could be stored in an apparently nonliving condition. When injected into a healthy


Diameter or length X width in millimicrons
750
Serratia marcescens (a bacterium)
450
Psittacosis (parrot fever virus)
270 x 230
Cowpox virus
115
Influenza virus
42
Equine encephalomyelitis virus
300 x 15
Tobacco mosaic virus
22
Yellow fever virus
12
Polio virus

15-1 Comparative sizes of a bacterium and selected viruses.

plant, the virus crystals produced the leaf mosaic disease. For his outstanding contribution in isolating the first virus, Dr. Stanley was awarded the highly coveted Nobel prize in chemistry in 1946.

The composition of viruses. In recent years scientists have determined the chemical composition of virus particles. A group of investigators at the University of California analyzed the ***shell,*** or outer covering, of the tobacco mosaic virus and found it to be composed of elongated protein fibers. Within this protein shell is a ***core*** of nucleic acid. In some viruses, including the tobacco mosaic, the core is RNA. In others it is DNA. It is interesting that the cells of organisms contain both of these nucleic acids, while viruses contain one or the other, but never both. The presence of these genetic materials in viruses tends to place them in the category of living organisms. The nucleic acid structure of the influenza virus, for example, gives it certain characteristics that are duplicated in new influenza virus particles as they are formed.



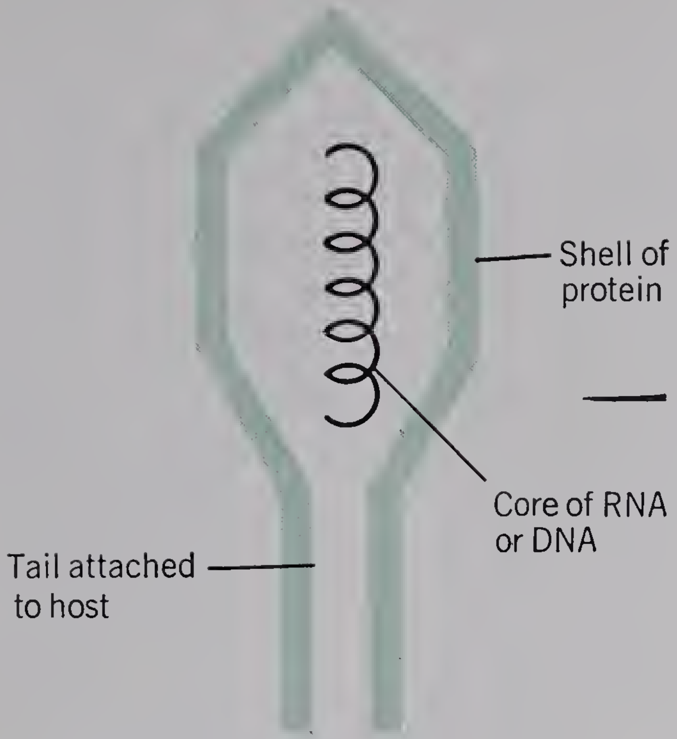
15-2 The rod-shaped particles of tobacco mosaic virus, magnified 100,000 times. (C. E. Hall)

Properties of viruses. It is in the activity of viruses that we find certain characteristics that make them different from cells and of questionable status as living things. A virus particle may be active only in direct association with the content of a living cell. Within the cell a virus may alter the enzyme systems and thus cause destruction of the cell. Removed from a cell a virus ceases all apparent activity but still retains its ability to infect a cell.

A virus cannot reproduce actively. That is, it cannot duplicate its own structure in the manner in which cells multiply by fission. A virus may reproduce passively, however, by altering the enzymes that control protein synthesis. In this way the virus uses the machinery of the cell to form virus particles rather than cell proteins. Thus a virus has an action similar to that of a gene. Could it be then that a virus particle is a gene without a "home" until it invades a cell?

In the discussion of the living condition in Chapter 2, we referred to various processes we associate with life. Cells carry on metabolic activities continuously. They use organic molecules for growth and oxidize fuel molecules to supply the energy necessary to support cellular activities. Are metabolic activities essential to a virus? An isolated virus requires no metabolic activity. Within a living cell it is capable of limited metabolic activity made possible by the machinery of the cell.

The properties of many viruses are



15-3 This schematic drawing shows the composition of a virus.

altered by the environment in which they are grown. This applies to the potency, or ***virulence*** (*vir*-yoo-lents), of many disease-producing viruses. For example, when rabies virus is grown in cells of the brain and spinal cord of dogs, its virulence for man and dogs increases. But if the virus is grown in rabbits it becomes less virulent for man and dogs but increases in virulence for rabbits. So, one might argue that the structure of a virus may be altered by the chemical nature and activity of the cell that produces it.

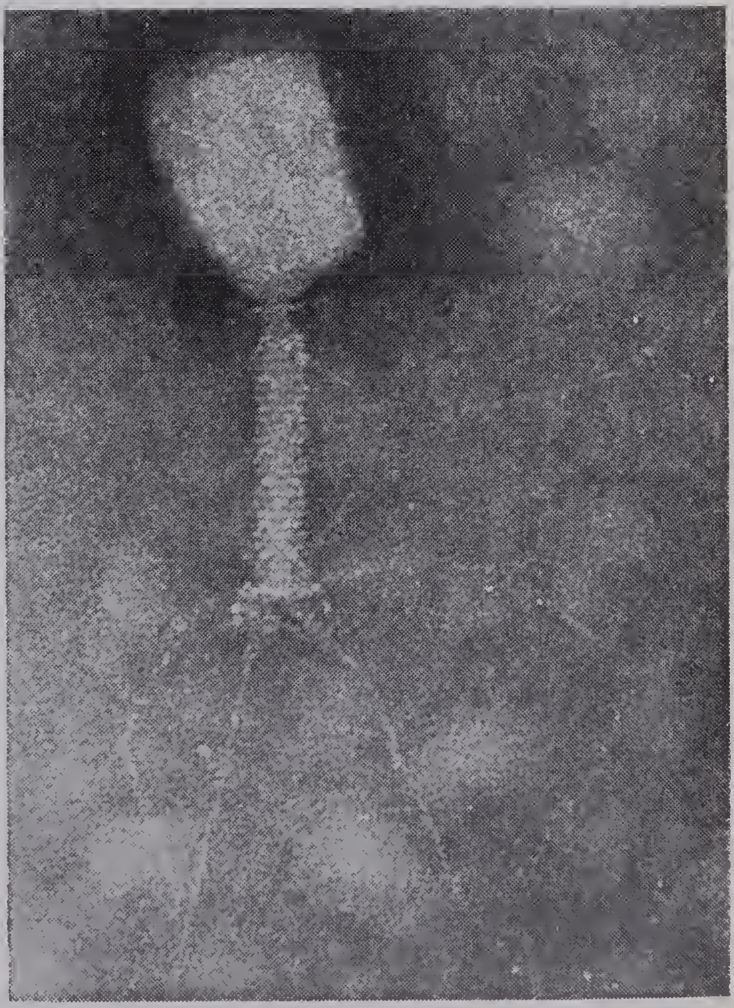
Further variations in the structure of viruses occur as mutations. More than 50 mutant strains of the tobacco mosaic have been discovered. These mutant strains differ in virulence and in the symptoms they produce in the host plant.

You have heard of highly virulent strains of influenza virus that strike populations at various intervals and of less virulent strains that cause much less serious infections. Perhaps the virus increases in virulence as it passes from one person to another during an epidemic. Or we may be dealing with various mutant viruses that differ in virulence.

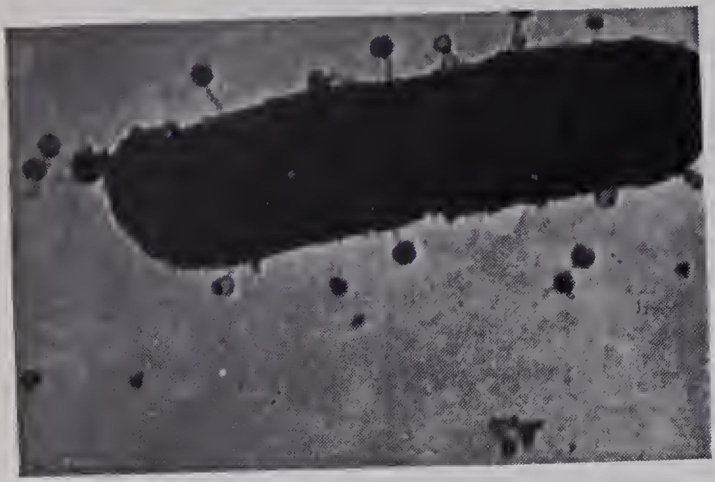
Classification of viruses. If a virus is a product of the disorganized machinery of a host cell, it is logical that a particular kind of cell would be necessary to produce a particular kind of virus. The relation of viruses to host cells is in fact highly specific. We classify viruses on the basis of their hosts, as follows:

1. *Bacterial viruses,* which invade the cells of bacteria.
2. *Plant viruses,* which live in the cells of seed plants, especially flowering plants.
3. *Human and animal viruses,* which live in human and animal cells.

Actually the virus-host relationship is even more specific than these large groups would indicate. Bacterial viruses invade only specific kinds of bac-



15-4 An electron micrograph of a virus magnified 500,000 times. (T. F. Anderson)



15-5 An electronmicrograph of a strain of bacteriophage attached to the cell of its host, the colon bacillus, magnified 54,000 times. (T. F. Anderson)

teria. Similarly a plant virus may be specific for the cells of flower petals, leaf tissues, or stem tissues of a particular kind of plant. A specific human or animal virus may require the environment of cells of the skin, the respiratory organs, or the nervous system. It might surprise you to know that some viruses are even more specific than this. Polio viruses attack only the cells of one kind of nerve in the brain and spinal cord. Similarly mumps is an infection of only one pair of salivary glands, and never invades the other pairs.

Bacteriophage viruses. Much of our knowledge of viruses has come from investigations of the bacterial viruses, often referred to as *phages* (fayjs). These are of the tadpole form, consisting of a round or many-sided head and a slender tail. The shell of a phage is composed of protein, while the core is exclusively DNA. Recently, RNA phages have been found.

The very first investigations of phages were conducted by two scientists working independently at about the same time. F. W. Twort, working in England in 1915, made an extensive study of a peculiar phenomenon he observed in the type of spherical bacterium called *staphylococcus* (staf-i-loh-*kahk*-us). For some unexplained reason, colonies of these bacteria growing in a culture suddenly developed holes, or ***plaques*** (plaks), as we call them today, which spread until the entire colony was destroyed. He found further that the agent that caused destruction of the bacteria could be transferred to other colonies with an inoculating needle. Two years later F. H. d'Herelle conducted similar studies of a mysterious disease of the dysentery bacillus, a rod-shaped bacterium, in France. He detected the same plaques that Twort had seen. d'Herelle first named this invisible agent of bacterial destruction ***bacteriophage***, or "bacteria eater."

The lytic cycle of a phage virus. While early investigators were able to demonstrate the action of a phage on bacteria, it remained for the electron microscope to reveal what actually happens during the destructive attack. Figure 15–5 is an example of an electron micrograph showing a greatly enlarged bacterial cell with phage viruses approaching it and others lodged, tail down, on the cell wall. Biologists have photographed all stages in the destruction of a bacterial cell.

We refer to the disintegration of a bacterium as a result of invasion by a phage as *lysis* (*ly*-sis). A phage that produces such a ***lytic cycle*** of destruction is designated as a ***virulent phage***. As we describe the lytic cycle shown in Fig. 15–6, check each numbered stage.

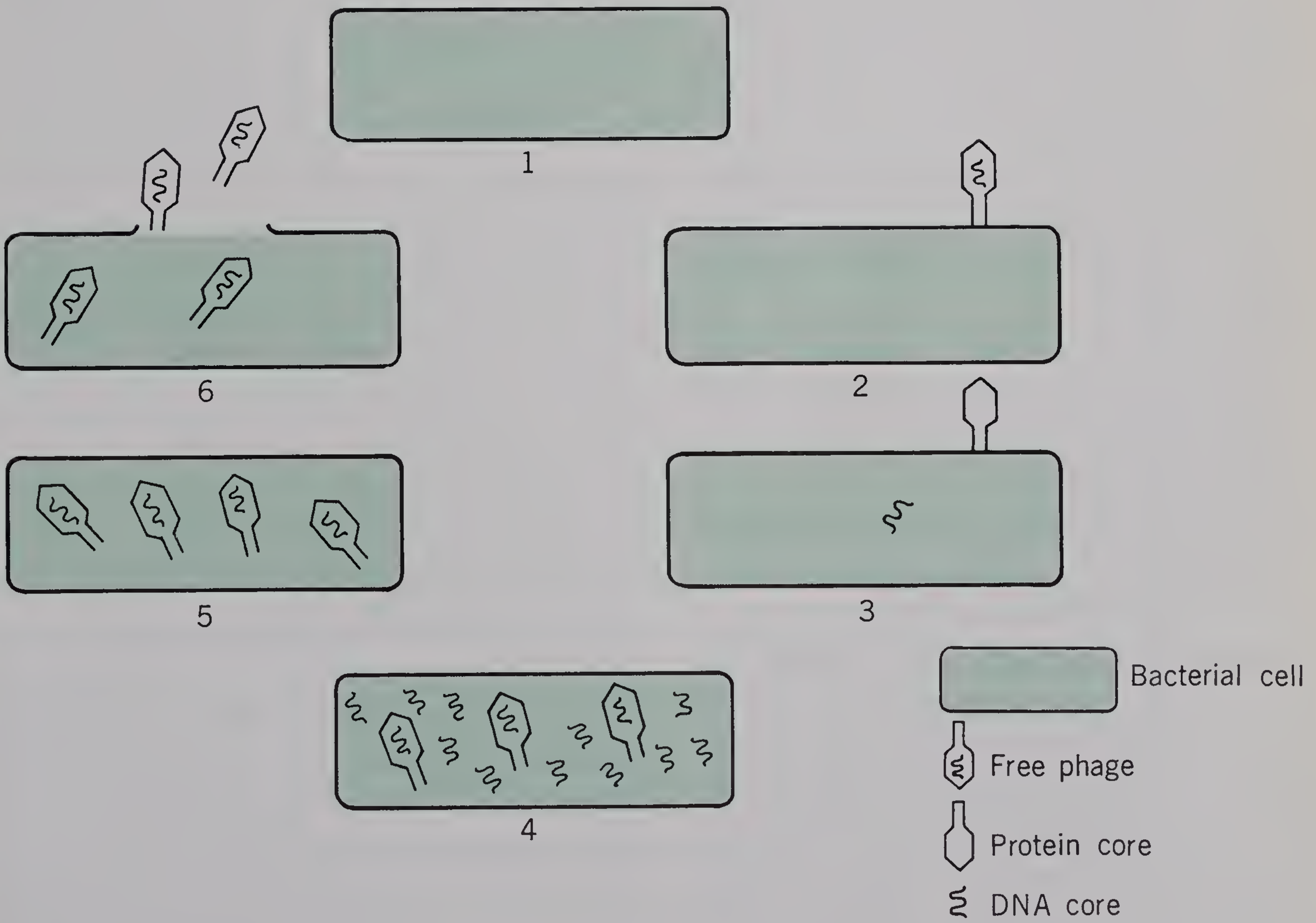
1. We begin with a normal, uninfected bacterium.
2. A phage virus has attached, tail down, to the cell wall of the bacterium by tiny hooks. An enzyme in the tail of the phage is dissolving an opening in the bacterial wall.
3. Having formed an opening in the

wall, the tail contracts and injects the DNA of the phage core into the bacterial cell. The empty protein phage shell remains outside.

4. Within a few minutes the phage DNA appears near the DNA of the host cell, which normally controls the formation of bacterial substances. The phage DNA takes over this control, and the machinery of the bacterium is used to synthesize phage DNA and protein molecules. The bacterium has become a virus factory.
5. Soon the bacterium contains 100 or more phage particles.
6. The bacterial cell disintegrates, releasing its phage content to attack 100 or more other bacterial cells.

This entire cycle, from entry of phage DNA to bursting of the bacterial cell and release of phage particles, requires up to 45 minutes. If each phage multiplies as much as 100 times in a lytic cycle, you can see how an entire colony of bacteria composed of many millions of cells can be destroyed within a few hours. The rate of bacterial destruction by a phage can be demonstrated in a broth culture. When a phage in the amount of one-billionth the quantity of bacteria is added to such a culture, all or nearly all of the bacteria are destroyed within three to fours hours.

Biologists have used the following analogy to describe a lytic phage cycle graphically. A tank moves up to the wall of an automobile factory in which an assembly line is in operation. The



15-6 The lytic cycle of destruction as produced by a virulent phage attacking a bacterium. The steps are described on pages 216 and 217.

tank breaks through the wall and its crew is discharged into the factory to disrupt the assembly line. Machines are reset and, using the same materials that were to have been automobiles, tanks begin to roll off the assembly line. Soon 100 or more tanks are rumbling through the plant. A wall is broken through and the tanks move out to attack other automobile factories, disrupt their assembly lines, and assemble more tanks!

Biologically we can draw several important conclusions from an understanding of the lytic cycle of a phage.

1. The free phage cannot reproduce. While it contains the DNA "blueprint" for synthesis of enzymes and other proteins, it cannot organize more of its own substance.
2. A phage particle is a nucleoprotein, consisting of a protein shell surrounding a DNA core. Both its composition and its action are similar to genes normally present in bacteria and other cells.
3. Bacterial genes control the synthesis of specific enzymes and other proteins characteristic of the particular organism.
4. Phage DNA within a bacterial cell functions as a gene and apparently substitutes its control for the action of bacterial genes.
5. The phage DNA alters the chemical machinery of the bacterial cell, causing it to synthesize phage particles.

Economic importance of bacterial viruses. At one time biologists thought virulent phages might offer a new and powerful medical weapon in the treatment of infectious diseases. Destroy disease-causing bacteria with a lytic phage — fight disease with disease! However logical and promising this procedure might seem, there are many problems and limitations. For one thing it would be very difficult to introduce the phage at the site of an infection, often deep in the body tissues. In other diseases the infection is widespread and it would be difficult for a phage to contact a sufficient number of bacteria to be effective. Still another problem is the fact that the human tissue environment may not be suitable for phage action. The conditions in the body are unlike those of a bacterial culture where phage action may be effective. For these reasons, and perhaps others, the possible medical uses of phages are not as promising as we once thought.

Phages are more important, however, in industries that require bacterial action. In the cheese industry, for example, certain bacteria are involved in the manufacturing process. Can you imagine the problem that arises if a phage is accidentally introduced and the cultures of these necessary bacteria are suddenly destroyed? This is a constant danger in industries that require bacterial processes.

Lysogenic phages — seeds of destruction. Certain phage viruses may invade bacterial cells without causing immediate destruction. When this happens the phage DNA discharged into the host cell may attach to a bacterial chromosome and become a foreign gene. When the bacterial genes replicate in preparation for the splitting of chromosomes during cell fission, the phage DNA also replicates. Each resulting daughter cell receives the phage DNA. In this manner the phage DNA is multiplied generation after generation as a "stowaway" in bacterial cells, causing no immediate damage but present as a potential "seed of destruction." At some future time, if conditions within the cell or in the cell environment are altered, the phage virus may become active, alter the normal synthesis of the cell, and produce a destructive lytic cycle. We refer to the delayed action of these phages as the ***lysogenic cycle.***

Certain lysogenic phages seem to produce two sets of bacterial descendents. The DNA in these phages does not replicate. When a division occurs one cell receives the phage DNA attached to a chromosome, while the other does not.

Plant viruses. Many viruses attack the cells of plants, especially flowering plants, causing serious damage and often killing the plant. The core of many of these viruses is RNA, rather than DNA as in the phage viruses. Plant viruses are often named for the host plant, the specific tissues they attack, and the nature of the symptoms of the infection.

We have already referred to the tobacco leaf mosaic virus, the first discovered. Similar mosaic infections occur in the tomato, potato, bean, and cucumber. One of the most interesting mosaic viruses causes an infection in the cells of flower petals. This results in light streaks or blotches that contrast with the normal petal coloration. One of the best examples of such a color variation due to a mosaic virus is the "broken" tulip. The unusual color pattern of these tulips has brought higher prices among gardeners, who grew them for many years without knowing that they were the result of a virus infection. Other plant virus diseases include the potato leaf roll, curly top of beet, peach rosette, aster yellows, and a serious disease of elm trees known as phloem necrosis.

Plant viruses may be spread in a number of ways. Insects that suck juices from leaves act often as agents of infection. Among these insects are plant lice, leaf hoppers, mealy bugs, and thrips. Virus infections are sometimes spread when gardeners handle diseased plants.

Human and animal viruses. Many familiar diseases of man and animals are caused by viruses. In most of them the virus invades only specific primary tissues in which the cell environment is suitable for multiplication of the virus particles. Symptoms of virus infections are as different as the viruses that cause them. Generally, however, a virus infection results in the disrupting of metabolic processes of the cells involved and damage or destruction of tissue. A lasting immunity remains after recovery from many virus infections, the common cold and influenza being notable exceptions. Biologists do not know the basis for this immunity.

Following is a list of the better-known virus diseases: smallpox, cowpox, chickenpox, shingles, cold sores and fever blisters, warts, influenza, measles, German measles (three-day measles), virus pneumonia, common cold, parrot fever, yellow fever, infectious hepatitis, infectious mononucleosis (glandular fever), and mumps.

Are viruses associated with cancer? One of the most encouraging developments in cancer research in recent years has been the discovery of a possible relationship between viruses and certain forms of cancer. Such an association might provide the basis for long-sought preventive measures or even for cures for certain forms of cancer. To date no viruses have been definitely linked with human cancers. But results of experiments with animals have been very encouraging. Dr. Ludwik Gross of the Veterans Administration Hospital in

New York City has found that a form of leukemia can be produced in mice by injecting an extract that contains a virus. Other investigators have produced more than 20 different kinds of malignant tumors in mice, guinea pigs, and hamsters with similar extracts.

When you think about what you have learned in this chapter, you may realize that it is reasonable to assume that some cancers may be produced by viruses. Cancer is abnormal growth of tissue, and growth is controlled by the DNA molecule. Since viruses alter the action of the DNA molecule, they may very well produce cancers.

IN CONCLUSION

Which side would you take now in a discussion of the status of a virus? Is a virus a living organism? Is it a by-product of life? Is it, perhaps, a cellular material that should remain in a cell but escapes to invade other cells?

As we continue the study of microbiology, we take a long step from molecules to cells. This leads us to perhaps the most simple and primitive forms of life, the bacteria. Simple as they are, however, we have no problem in considering bacteria living organisms, for all have a cellular organization.

BIOLOGICALLY SPEAKING

bacteriophage
core
filterable virus
lysogenic cycle
lytic cycle
plaque
shell
virulence
virulent phage

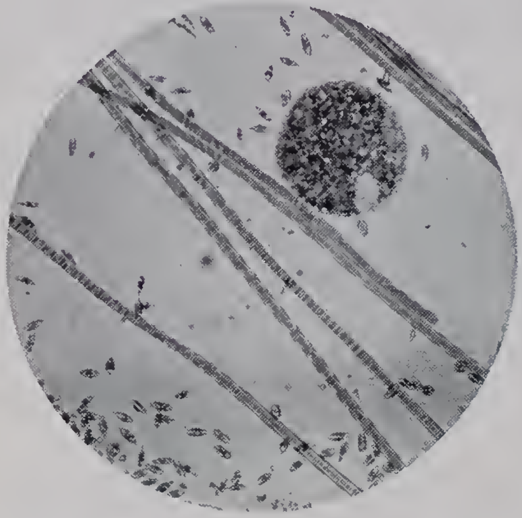
QUESTIONS FOR REVIEW

1. Account for the name *filterable virus.*
2. Describe four shapes of virus particles.
3. From what source did Dr. Wendell Stanley isolate the first virus?
4. What organic substance forms the shell of a virus? the core?
5. What is meant by the virulence of a virus?
6. Classify viruses into three groups on the basis of the host organism.
7. What contributions in virology were made by F. W. Twort and F. H. d'Herelle?
8. Describe the lytic cycle of a phage virus.
9. List several limitations in the medical use of a phage to treat infectious diseases.
10. List several plant virus diseases.
11. Account for the unusual coloration of a "broken" tulip.
12. In what respect is a lysogenic phage a potential "seed of destruction"?
13. List several well-known human virus diseases.

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss various factors that may alter the virulence of a virus.
2. Discuss several biological principles illustrated in the lytic cycle of a phage virus.
3. Discuss passive reproduction of a virus as compared with active reproduction of a cellular organism.
4. Account for the high degree of specificity of viruses.
5. Explain the delayed action aspect of a lysogenic phage.
6. Explain why it is biologically reasonable to assume that some forms of cancer may be caused by viruses.

CHAPTER 16



BACTERIA AND RELATED ORGANISMS

Bacteria – primitive cellular organisms. As we proceed from the study of viruses to bacteria and their relatives, we shift from molecular particles to primitive cellular organisms. Many biologists believe that bacteria were the first forms of life on the earth, appearing late in the Archeozoic era (see Fig. 13–1). Long before there were green plants capable of photosynthesis, certain primitive bacteria may have utilized energy from iron, sulfur, and nitrogen compounds instead of the sun. Geologists think that the extensive deposits of iron ore we are using today are the result of bacterial action during ancient geologic times. Later, when green plants began building up stores of organic compounds, other kinds of bacteria began using them as a food supply. Still other bacteria invaded the tissues of the plants themselves as well as the bodies of animals.

Bacteria have survived through the ages and have increased their numbers until today they are the most abundant form of life. They live, invisibly, almost everywhere. They thrive in the air, in water, in food, in the soil, and in the bodies of plants and animals. In fact, any environment that can support life in any form will have its population of bacteria.

Louis Pasteur – the father of bacteriology. In the history of biology, there have been a few truly great investigators who have changed the direction of the science and opened a whole new field for experimentation. Louis Pasteur was such a figure. This great scientist of a century ago is no stranger to you. Do you remember the goose-necked flasks he devised to deal a crushing blow to the belief in spontaneous generation? This was only a small part of this great man's contribution to science. Let's take another look at the man who introduced microorganisms to the world, revolutionized the practice of medicine, and provided much of the basis for the modern science of bacteriology.

Pasteur was born in Dole, France, in 1822. He graduated from college at an early age with a brilliant record of achievement in chemistry. In 1854, while a young man of 32, he was appointed professor of chemistry and dean of the University of Lille (leel). It was here that circumstances combined to alter the course of biological science for generations to come.

In the city of Lille, alcohol was manufactured by fermenting sugar-beet juice in large vats. Chemists of his day thought that alcoholic fermentation was a purely chemical process. They had seen tiny yeast cells growing in ferment-

16-1 The great French scientist Louis Pasteur in his laboratory. (© 1962, Parke, Davis & Co.)

ing beet and fruit juices but had always considered them to be products of spontaneous generation, in no way connected with the fermentation process.

Then, one day, a serious problem arose at the fermentation plant. In several of the vats, the juice was souring rather than becoming alcoholic. What had happened to change the chemical process? Pasteur was called in to try to find the answer.

In his laboratory, with his microscope, Pasteur examined the juice that was fermenting as it should. Dispersed through the liquid were numerous oval yeast cells. Over a period of several hours he watched the cells multiply by forming chains of buds. As the cells increased in number, the alcohol content increased. Were the yeast cells producing the alcohol? The answer to this question might be found in the sour juice. Accordingly, Pasteur examined a drop of liquid from a vat of sour juice. Here he found an entirely different population of microorganisms. Instead of yeast cells he found quivering rods, smaller than yeasts but apparently alive. He found that this liquid contained lactic acid rather than alcohol. Furthermore, the lactic acid content increased with the germ population.

This discovery led Pasteur to more extensive studies of fermentation. Three years later he set up a small laboratory in Paris. Here he proved that fermentations are associated with microorganisms and that the products formed depend on the organism involved. Yeasts produce alcohol. Bacteria may form lactic acid in beet juice and in milk.

Fortunately Pasteur did not end his explorations in microbiology with fermentation studies. Far more important than fermentation was the presentation of his germ theory to the scientific world. If bacteria could ferment beet juice, might other kinds cause disease? These are accounts yet to be discussed in the life of this remarkable chemist who became one of the greatest biologists of all time.

What are bacteria? Since Pasteur observed bacteria, they have been considered both animals and plants. Until recently they were classified with the fungi in the old phylum Thallophyta of the plant kingdom. More recently biologists have avoided calling them anything but organisms by placing them in the kingdom Protista. Together with close relatives they constitute the protist phylum ***Schizomycophyta*** (*skiz*-o-my-*kahf*-i-ta), a name meaning "fission fungi."

If you use a virus for comparison, bacteria are large. You will recall that a single infected bacterial cell may contain as many as 100 phage particles.

However, compared to the cells of most other organisms, bacteria are extremely small. We used millimicrons to measure viruses. Bacteria are measured in microns (one micron = 0.001 millimeter). Spherical bacteria range in size from about 0.5 to 1.5 μ in diameter, while the rod-shaped forms average from about 0.2 to 2 μ in width and from 0.5 to as much as 10 μ in length. The average length of bacteria is approximately 1.5 μ. Converting these figures to inches, bacteria range from about 1/50,000 to 1/10,000 of an inch. If these figures mean little to you, consider that several thousand bacteria could be placed on the period at the end of this sentence or that a small drop of water may contain as many as 50 million bacteria.

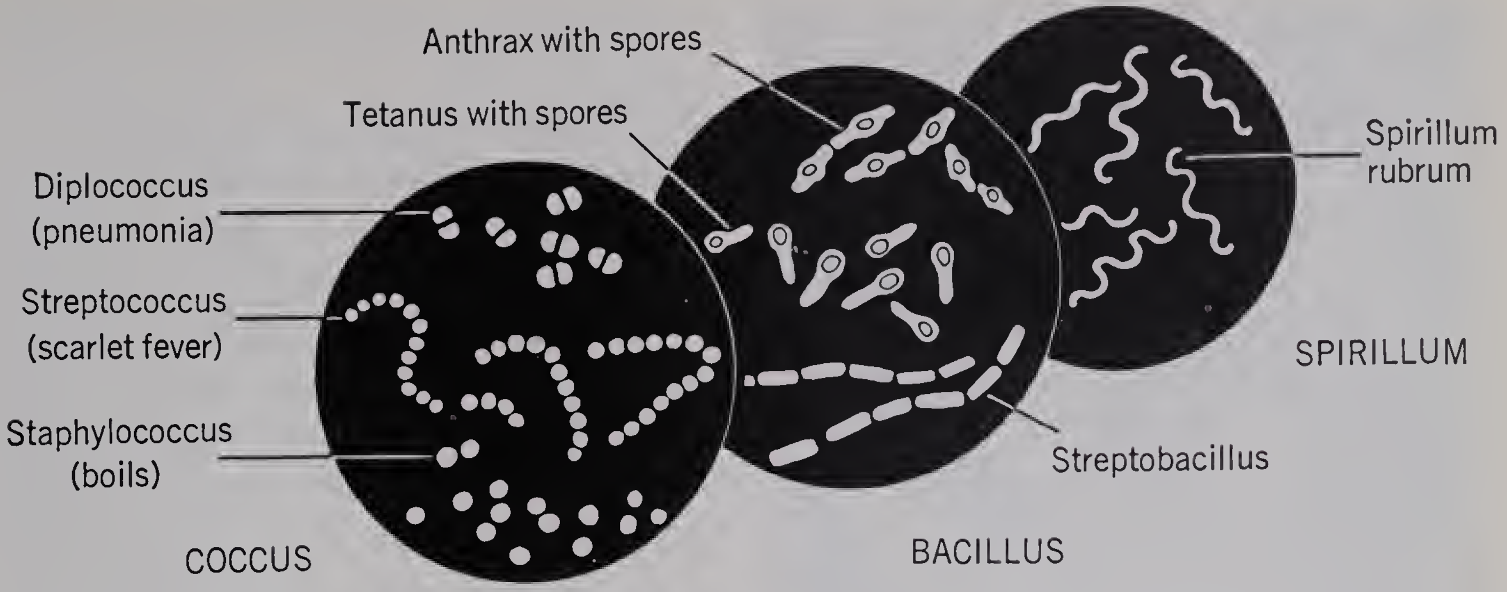
You can see bacteria with the high-power magnification of your microscope (430X) and even determine their shape. Additional magnification (1,000 to 1,500X) is necessary to see them clearly. However, no light microscope can magnify sufficiently to reveal most of the internal structures of bacterial cells. For this we need the 50,000 to 100,000 enlargement of the electron microscope.

Forms of bacteria. While bacteria vary greatly in size, their cells are of three basic shapes. Some bacterial cells tend to exist singly when grown in liquid cultures or broths, while others often remain attached after cell division and form colonies of cells. We can classify the basic cell shapes and groupings as follows:

- ***coccus*** (pl. cocci) — cells sphere-shaped or globular
  - *diplococcus* — cells often joined in pairs or short filaments
  - *streptococcus* — filaments or strings of cells
  - *staphylococcus* — clusters of cells
  - *tetrad* — groups of four cells
  - *sarcina* — cubes or packets of cells
- ***bacillus*** (pl. bacilli) — cells elongated or rod-shaped
  - *streptobacillus* — cells joined end to end forming a filament or thread
- ***spirillum*** (pl. spirilla) — cells in the form of bent rods or corkscrews

Structure of a bacterial cell. Bacterial cells are surrounded by a ***slime layer*** of varying thickness. This gelatinous coat may protect the cell from unfavorable environmental conditions and enables it to stick to the surface of a food supply or to a host cell or organism. Some bacteria have a thick slime layer referred to as a ***capsule.*** Perhaps you remember from our discussion of transformation in Chapter 10 that the pneumonia organism (*Diplococcus pneumoniae*) is an example of such an encapsulated organism. It is interesting that the presence of the capsule is an indication of the virulence of the pneumonia organism. Encapsulated forms produce a serious infection. The capsule may protect these bacteria from the normal body defenses against infectious organisms. Strains of pneumonia organisms lacking a capsule are low in virulence or even noninfectious. Perhaps these organisms are easily destroyed by the body defenses. Some bacterial masses form gelatinous coatings. Did you ever remove the gelatinous "mother of vinegar" from a vinegar jar? This is such a bacterial mass. In other species, including iron bacteria, a ***sheath*** may surround an entire filament of bacteria. Iron compounds are often deposited in the sheaths of these bacteria, forming the reddish-brown, slimy masses often seen in streams.

Beneath the slime layer or capsule is an obvious ***cell wall.*** This gives the

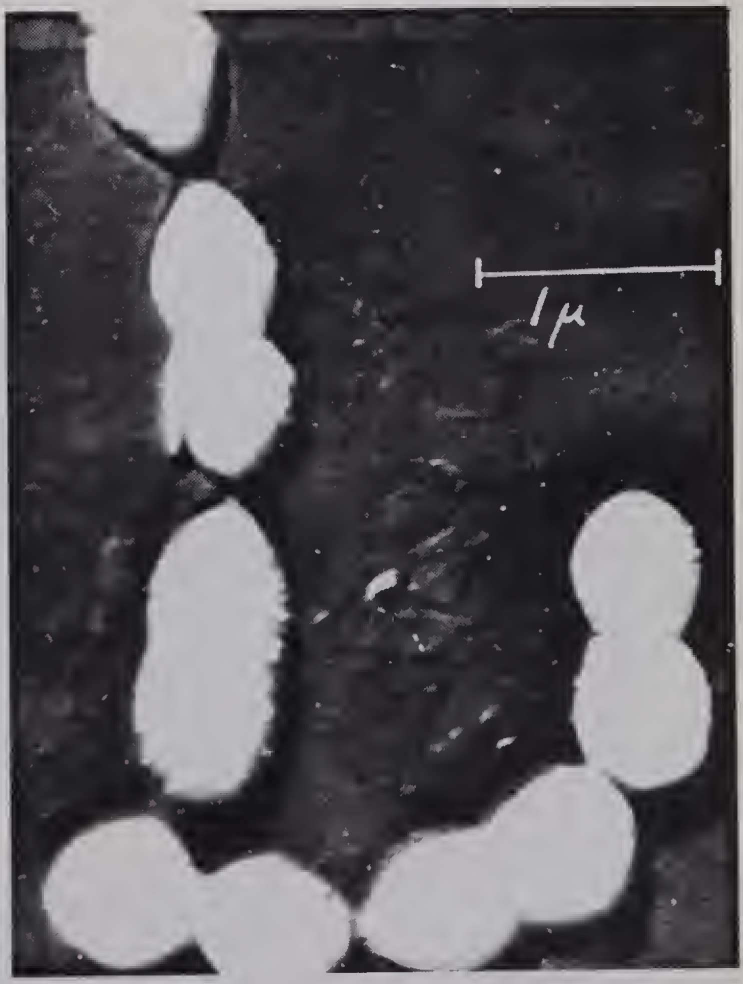

Anthrax with spores
Tetanus with spores
Diplococcus (pneumonia)
Streptococcus (scarlet fever)
Staphylococcus (boils)
COCCUS
Spirillum rubrum
SPIRILLUM
Streptobacillus
BACILLUS

16-2 This drawing illustrates the three great groups of bacteria with some examples of each type.

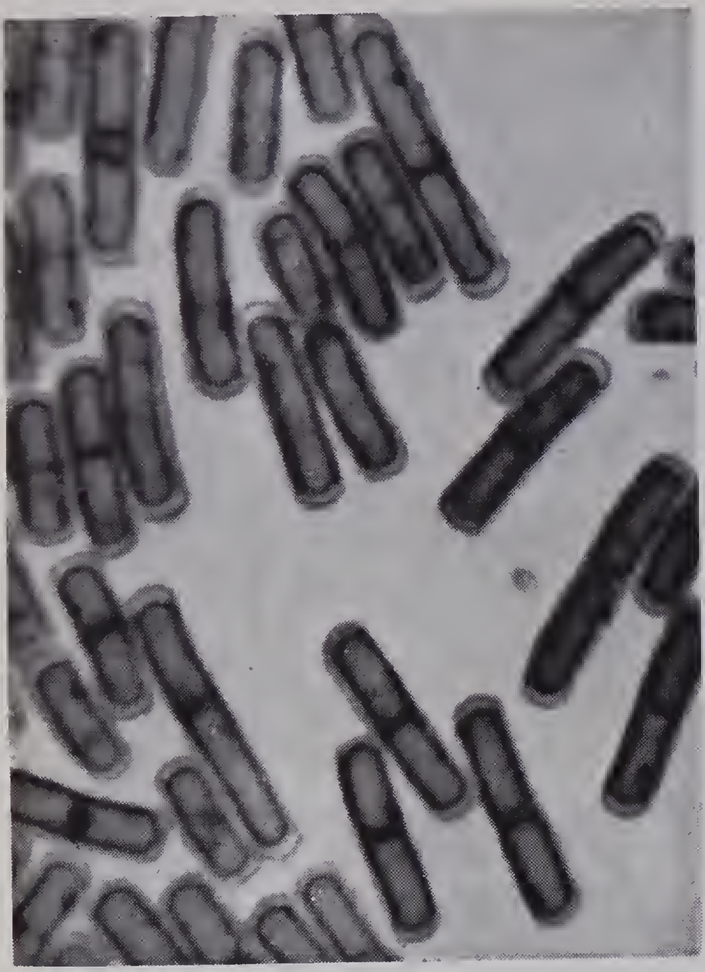
cell its characteristic shape. A thin, flexible ***plasma membrane*** lies just beneath the cell wall and marks the outer edge of the cytoplasm. Bacteria lack a nuclear membrane. However, they have been found to contain DNA in genes that are concentrated in chromatin bodies lying near the center of the cell. Some biologists believe that these bodies constitute a single bacterial chromosome. Mitosis does not occur in bacteria, although there is division of the chromatin bodies each time a cell divides. This results in equal distribution of DNA in daughter cells.

Many bacteria contain granules of stored food and other materials dispersed through the cytoplasm. A few also contain vacuoles of water and dissolved materials. Mitochondria, the vital centers of respiration in other cells, are lacking in bacteria. Respiratory enzymes, usually found in mitochondria, seem to be concentrated on the cell membrane of a bacterial cell.

Motility in bacteria. Various bacillus and spirillum forms of bacteria are equipped with threadlike whips, or ***flagella*** (fla-*jel*-a), which propel the cell through water and other fluids. Flagella may be found singly or in tufts at either or both ends of a bacterial cell. In some forms flagella are found all around the cell. Flagella are visible only when they are treated with special stains. Under the highest magnifica-



16-3 An electronmicrograph of *Diplococcus pneumoniae.* (Robert Austrian and *Journal of Experimental Medicine*)



16-4 This electronmicrograph of *Bacillis cereus* shows the cell wall and plasma membrane clearly. (C. F. Robinow)

tion of the light microscope, they appear as minute threads. The electron microscope shows them to be cytoplasmic extensions that project through openings in the cell wall. Flagella are strands of protein molecules resembling the microscopic fibers composing muscle. Thus, in the beating flagella of bacteria, we may have the basis for the muscle contractions of animal organisms.

You may recognize motility in bacteria by their random movement in a microscopic field. All cells move independently in a quivering, twisting manner. This ***true movement*** by means of flagella should not be confused with an oscillating or bouncing motion, known as ***Brownian movement.*** This motion results from the jarring of very small bacteria, especially coccus forms, by the movement of molecules or other particles in a fluid.

Conditions for growth of bacteria. In discussing various environmental requirements for the growth of bacteria, we need to make a distinction between activity and survival. Bacteria have the property of remaining inactive when conditions for growth are lacking. For example, they may float high in the air or lie on an object in an inactive condition. Then, when environmental conditions are favorable, they may enter a period of very rapid growth and reproduction.

A *suitable temperature* is essential for bacterial activity, but this temperature varies greatly with different species. The majority of bacteria thrive at moderate temperatures, ranging from 80 to 100° F. Those that cause human infections grow best at 98.6° F (37° C), or normal body temperature. But there are many bacteria that grow best at much lower temperatures, ranging from 32° F to an upper limit of 85° F. These bacteria occur in ocean depths, in the cold soils of the far north, and high in the stratosphere. At the other extreme are bacteria that thrive at temperatures ranging from 110° F to as high as 185° F. These are found in hot springs and in the hot environment of decomposing sewage, silage, and other plant materials.

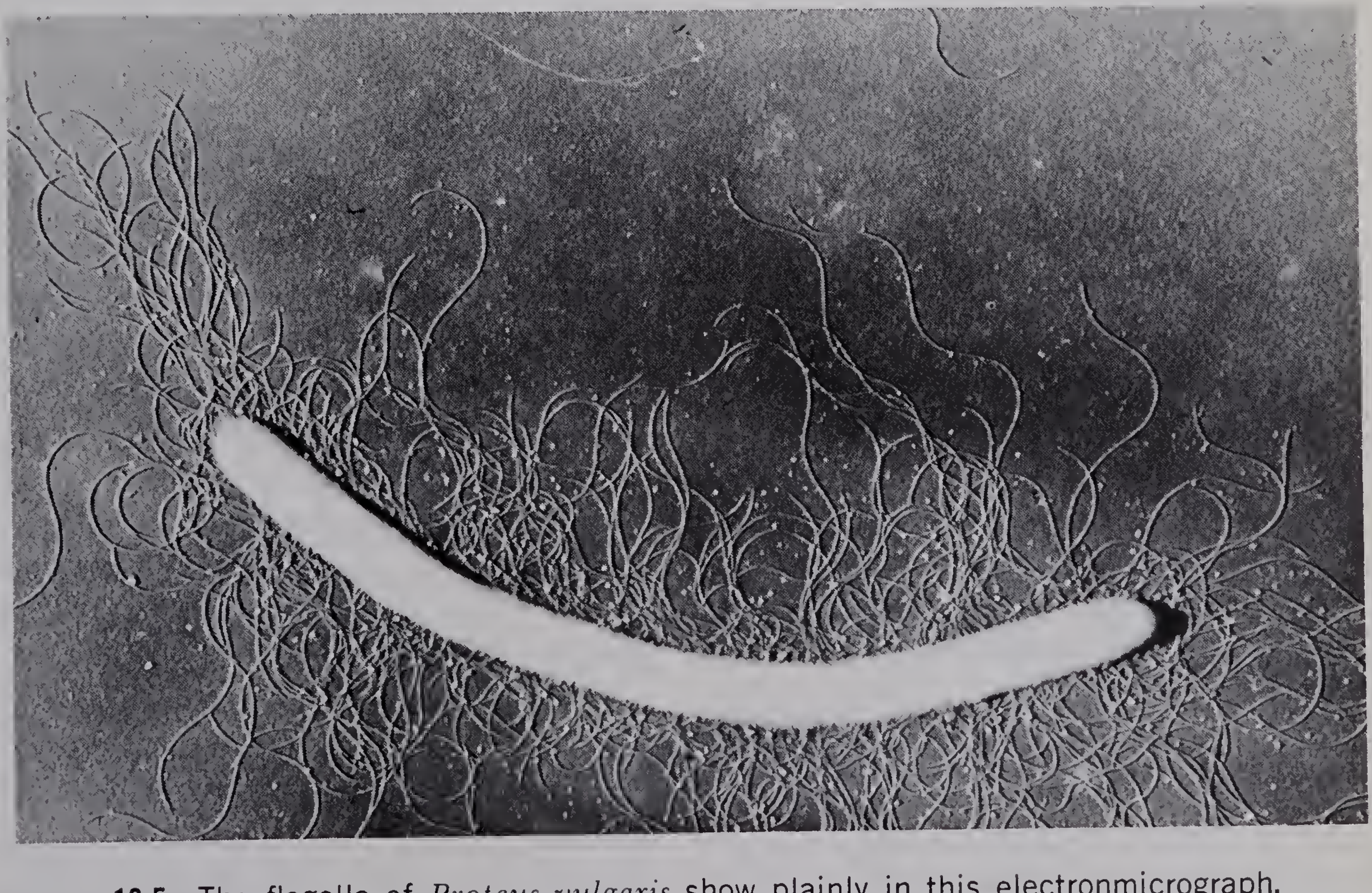
Moisture is another growth requirement for bacteria. Bacterial cells are 90 percent water. In dry surroundings water loss makes the cells inactive and prolonged dryness will kill them.

Darkness is also a condition for best bacterial activity. Exposure to sunlight may retard growth, and ultraviolet radiation actually kills cells. We make use of radiation effects on bacteria when we sterilize the air in hospital surgeries with lamps that emit ultraviolet rays.

A *suitable food source* is still another requirement for the growth of bacteria. In this respect bacteria vary greatly. Some bacteria are highly specific in their food needs. Most pathogenic bacteria require living tissues or substances similar to them in chemical composition. Many bacteria are more tolerant and can live on a wide variety of food materials.

Bacterial nutrition. The majority of bacteria lack the property of synthesizing the substances they require and must therefore live in contact with preformed organic matter. In this respect they are *heterotrophic.* The lack of ability to carry on photosynthesis puts them in direct competition with man and other animals for food. Bacteria we classify as ***saprophytes*** (sap-ro-*fyts*) utilize dead organic matter or nonliving organic substances such as food products. ***Parasites,*** on the other hand, invade the bodies of plants and animals and take their nourishment directly from living tissue. We refer to the organism supporting the parasite as the ***host.***

Bacteria secrete powerful enzymes. These organic catalysts are essential in causing chemical changes both inside and outside the bacterial cell. Many of these are digestive enzymes. An enzyme acts only on one kind of food substance. Thus, the food source or host required by a specific kind of bacterium is determined by the enzymes it produces. Enzyme action simplifies complex organic molecules and converts them to soluble substances that can be absorbed through the cell wall and membrane. Enzymes allow saprophytes to use a variety of organic materials, many of which are useless to other forms of life. Among these are wood and other cellulose materials. Parasitic bacteria lack many of the enzyme sys-



16-5 The flagella of *Proteus vulgaris* show plainly in this electronmicrograph. (Houwink, Van Iterson and *Biochimica et Biophysica Acta*)

16-6 An interesting microorganism found in a soil-sampling program is transferred from the Petri dish on which it grew with other types to a tube of nutrient medium of its own. (Chas. Pfizer & Co.)

tems found in saprophytic organisms. This explains why they must live in contact with living tissue and utilize enzyme action of the host cells.

A relatively small number of bacteria are *autotrophic*. These organisms synthesize their own organic compounds. Certain of these organisms, designated as *chemotropic*, or *chemosynthetic*, utilize inorganic compounds as a source of energy. Some of these oxidize iron compounds. Others use sulfur compounds. Still others, including nitrite and nitrate bacteria, oxidize nitrogen compounds. Perhaps the most unusual bacteria are those capable of photosynthesis. These *photosynthetic bacteria* contain bacteriochlorophyll, a pigment similar to the chlorophyll of higher plants. The pigments in these bacteria are dispersed on intracellular cell membrane systems rather than localized in chloroplasts.

Bacterial respiration. Atmospheric oxygen is an important factor in the growth of bacteria. Among the many kinds of bacteria, we find both extremes in free oxygen relations, some requiring its presence and others requiring its absence. Others are between these two extremes.

Certain bacteria require atmospheric oxygen for respiration in the same manner as most plants and animals. We refer to these as ***obligate aerobes*** (*air*-ohbs), which include such organisms as the diphtheria and tuberculosis bacilli and cholera bacteria. These bacteria split glucose molecules and form carbon dioxide and water during respiration.

At the other extreme are organisms classed as ***obligate anaerobes*** (an-*air*-ohbs). These bacteria cannot grow in the presence of atmospheric oxygen. Among the best known obligate anaerobes are the tetanus and botulism organisms.

The greatest number of bacteria are ***facultative anaerobes,*** which grow best as aerobes but may grow, at least to some extent, as anaerobes. Among these organisms we find the common bacillus of the human intestine (*Escherichia coli*) [esh-er-*ik*-ee-a *koh*-ly] and such pathogens as the typhoid, diphtheria, and scarlet fever bacteria. Much less frequent are the ***facultative aerobes,*** which are primarily anaerobes but are able to maintain limited activity in the presence of free oxygen.

We often refer to anaerobic respiration as *fermentation*. The products of fermentation vary with the organisms involved. In the bacteria that produce alcohol by fermentation, glucose molecules are split and a small amount of energy is released. Carbon dioxide and pyruvic acid are formed. Pyruvic acid is then reduced (hydrogen is added) to form ethyl alcohol. We can summarize this fermentation reaction in the following simplified equation:

$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow 2\underset{\text{ethyl alcohol}}{C_2H_5OH} + 2\underset{\text{carbon dioxide}}{CO_2} + \text{energy}$$

Other bacteria produce lactic acid by fermentation. In this reaction a glucose molecule is split with the formation of pyruvic acid, which is then reduced (hydrogen is added) to lactic acid. A small amount of energy is released with the splitting of the glucose molecule. We may summarize this process in the following simplified equation:

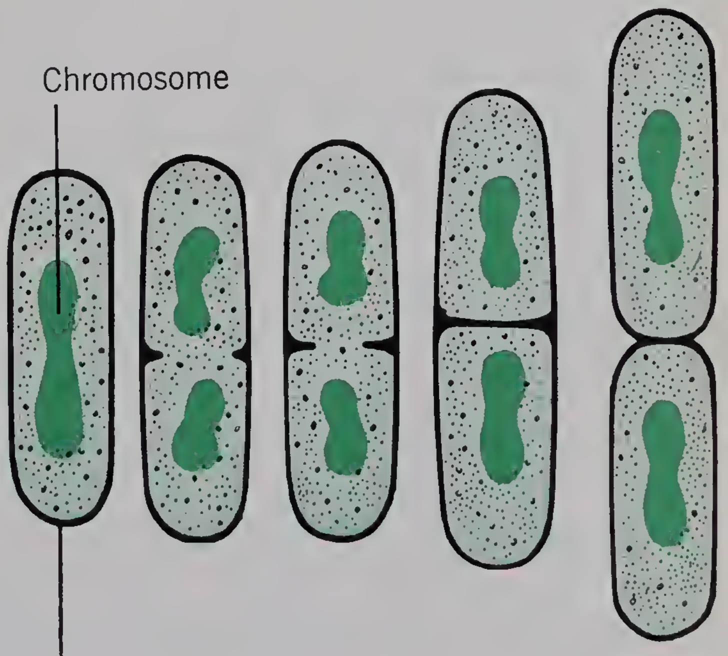
$$\underset{\text{glucose}}{C_6H_{12}O_6} \rightarrow 2\underset{\text{lactic acid}}{C_3H_6O_3} + \text{energy}$$

A few bacteria carry on *true anaerobic respiration*, which differs from fermentation. One of the more familiar true anaerobic reactions occurs in the formation of methane. In this reaction hydrogen is combined with carbon dioxide, forming methane and water and releasing energy as follows:

$$4\underset{\text{hydrogen}}{H_2} + \underset{\text{carbon dioxide}}{CO_2} \rightarrow \underset{\text{methane}}{CH_4} + 2\underset{\text{water}}{H_2O} + \text{energy}$$

Methane is called marsh gas because it may be seen bubbling to the surface from decomposing organic matter accumulated in the bottom of bogs, swamps, and ponds. It is also present in natural gas.

Bacterial reproduction. Bacteria multiply by dividing. They accomplish this apparent mathematical impossibility by fission, or cell division. They multiply at an amazing rate when conditions for growth are ideal. Consider that a cell may be formed by a division of a mother cell, grow to maturity, and start dividing again in a period of only 20 minutes! This may not seem alarming until you begin to calculate the results. Start with one cell that divides and becomes two in 20 minutes. These become four in 40 minutes and eight at the end of an hour. How many would be formed in 12 hours? in 24 hours? If this rate of increase continued for 24 hours, a mass of bacteria weighing over 2,000 tons would be formed! If this rate of increase continued for another 24-hour period, the mass would weigh more than 20,000,000,000,000,000,000,000,000 tons! Why, then, don't bacteria cover the earth and crowd out all other living things as you might believe would happen?



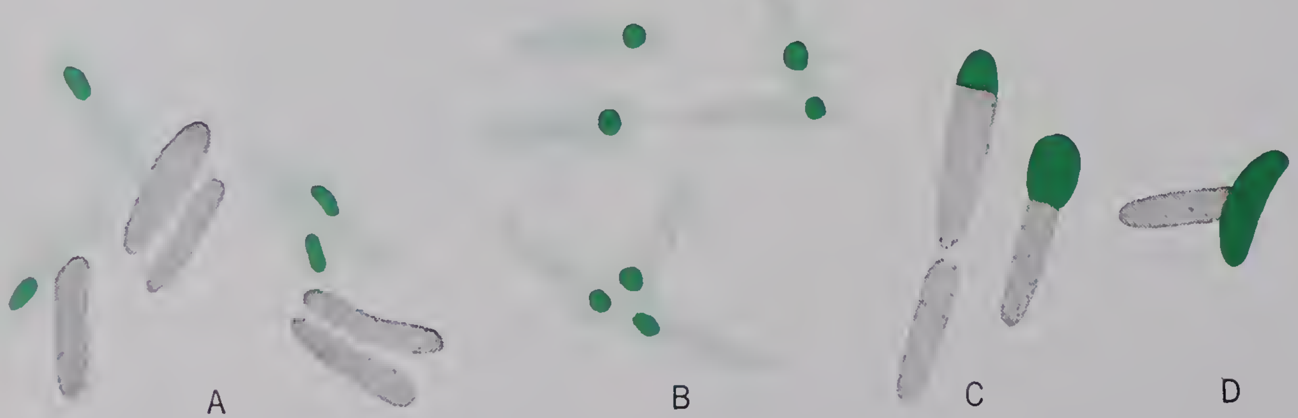
16-7 Bacterial reproduction by fission. Note that the chromosome divides first, followed by a division of the cell proper.

Suppose we start with a single bacterium in a Petri-dish culture containing a culture medium such as nutrient agar. Cultures such as this are commonly used to grow bacteria in the laboratory. After a brief period of adjustment to the culture medium, the cell divides. For a few hours growth and cell divisions occur rapidly. If divisions occur as rapidly as once in 20 minutes, the original cell will produce 512 organisms at the end of three hours. As the mass increases in size, the problem of *mechanical crowding* also increases. With this crowding comes *competition for food*. There is also an *accumulation of metabolic wastes*, which must be excreted through the cell membrane and wall of each organism. Within a short time these factors reduce the rate of growth and reproduction. The mass continues to increase in size, however, and after 24 hours a visible colony composed of several billion cells is formed. This colony will continue to increase in size for perhaps another 24 hours, but the rate of division during this period will be even more reduced. By the end of 72 hours cells may be dying or becoming inactive.

Spore formation. Many bacillus bacteria form *endospores* when conditions for growth and cell division become unfavorable. Endospores are formed singly as the cell content, including the genetic material, is drawn into a spherical or oval mass which becomes encased in a single or double protective membrane. Bacterial endospores can endure almost unbelievable conditions. They may survive in extremely dry conditions and resist boiling water. Extreme cold does not destroy them. Scientists were surprised to find bacterial spores in deep layers of ice in the Antarctic a few years ago. Apparently they had been lying in the ice many thousands and perhaps millions of years. Yet, when these spores were placed in favorable growing conditions, they were able to form active bacillus cells! This is undoubtedly a record for existence of living substances in a resting state.

Endospore formation is not a form of multiplication. A cell forms a single spore which may germinate after a period and become an active cell again. But the number of bacteria is not increased by spore formation. Spores are merely stages in which certain bacilli resist unfavorable environmental conditions.

The resistance of spores creates medical problems. Many procedures used to destroy active bacterial cells do not kill spores. This applies to boiling



16-8 A: Botulinus bacteria and spores. B: Tetanus spores. C and D: Spore germination.

and to the use of certain cleansing agents and antiseptics. Tetanus spores are a constant infection problem. Active tetanus bacteria are restricted to anaerobic environments, which is why a closed wound is an ideal site for tetanus infection. Tetanus spores, however, are abundant in the soil, on objects, and even in the air.

Sexual reproduction in bacteria. Bacterial cells can apparently reproduce by fission indefinitely. For many years, however, biologists have wondered if sexual reproduction occurred in organisms as low in the scale of development as bacteria. Recent research has established that sexual reproduction does occur, at least in some species of bacteria, and that it may occur in all bacteria.

Extensive studies of sexual reproduction in bacteria have been conducted with *E. coli*, an organism often referred to as the colon bacillus because it normally lives in the human large intestine. Two mating types of this organism have been discovered. One is designated as male, the other as female. In this bacterium, maleness results from the presence of genetic particles that are not present on the chromosome. Femaleness results from the lack of these particles. When male and female strains of *E. coli* are mixed in a fluid suspension such as a broth culture, the cells come together. A cytoplasmic bridge joins the two cells. The male cell injects its chromosome along with its sex-determining particles into the female cell. Soon after this process the male cells, lacking genetic materials, die. What do you suppose happens to the female cells? Having received the male genetic particles, they change to male cells.

What is the significance of sexual reproduction in bacteria? Remember that when organisms reproduce sexually, both parents contribute genetic material. The resulting new genetic combinations may produce offspring that differ from either parent. These offspring may be more favorably adapted to their environment and have better chances of survival. In the mating process that occurs in *E. coli*, the male cell that results contains genetic material from both the male and female strains. The offspring arising from fission of this cell will in turn contain newly combined genetic material. It may be that this sexual process has been important in producing the many types of bacteria existing today.

Beneficial activities of soil bacteria. We have heard so much about the disease-causing, or ***pathogenic*** (path-o-*jen*-ik), bacteria that we easily get the impression that all bacteria are dangerous to health. Quite to the contrary, the majority of bacteria are entirely harmless, having no direct relation to our lives or to our economy. Many other bacteria are beneficial to man. As a matter of fact, our very lives depend on the bacteria that live in the soil. To understand the vital role these bacteria play, we need to consider a much larger segment of a biological society.

Green plants absorb minerals from the soil and use them in synthesizing organic compounds. Animals consume plants and rearrange these compounds to meet their specific needs. In this manner many of the chemical requirements for life come directly or indirectly from the soil. When a plant or animal dies, the chemical substances composing it are left in a complex form — products of life, yet in no chemical condition to supply the needs of another generation of plants and animals. What if all of the organisms that have populated the earth during the past few thousands years were still lying about in their original chemical condition? Would there be any room on the earth's surface for new generations? Would there still be sufficient chemical supplies in the earth's crust to form these new organisms?

You know, of course, that organisms decay after death. They are decomposed and their materials are returned to the earth and atmosphere. Do you know, however, that this is largely bacterial activity? During decay and putrefaction, bacteria and other soil organisms, including molds, break down complex molecules in dead plant and animal matter and form simpler chemical compounds. In this way, the matter that once composed a living organism is broken down into substances that can be absorbed by a plant root and used in another series of building activities in a new generation of organisms. Build up and break down — synthesize and decompose. Matter is coming and going constantly in chemical cycles involving organisms. Bacteria are vital in these chemical cycles. Since chemical cycles involve many kinds of organisms and the interrelation of their lives, we have reserved a full discussion of them for an ecological study in Unit Eight.

Bacteria in industrial processes. Bacteria play an important part in the processing of many foods and other products of industry. We will discuss a few of these processes briefly.

Vinegar making involves two kinds of microorganisms: yeasts and bacteria. In producing vinegar, yeasts ferment sugar in fruit juice and change it to alcohol. Acetic acid bacteria (*Acetobacter*) [as-ee-to-*bak*-ter] then oxidize the alcohol, changing it to acetic acid. Commercial vinegars contain about four percent acetic acid.

Sauerkraut making is another process involving bacteria. In preparing sauerkraut, cabbage leaves are shredded and put in an airtight jar. Anaerobic bacteria (*Lactobacillus*) [*lak*-toh-ba-*sil*-us] ferment the sugar in the cabbage leaves and convert it to lactic acid. A small amount of carbon dioxide and alcohol are formed in the process.

Several kinds of bacteria are involved in the *tanning of leather*. After a hide has been preserved by drying or salting, it is soaked and scraped to remove excess flesh. The hair is removed either by bacterial action or chemical treatment. The final tanning takes place in large tanks or vats in which bacteria and other organisms attack the hides and make them pliable.

The *retting of flax* is a process many centuries old. The slender stems of the flax plant contain fibers that are extracted and processed as linen. When the stem is cut, the fibers are securely joined to other stem tissues. But if the flax plants are tied in bundles and submerged in tanks of warm water, soluble materials dissolve and form a culture medium suitable for growing anaerobic bacteria (*Clostridium*) [klah-*strid*-ee-um]. These organisms ferment the pectin that holds the fibers in the stem. After 10 to 14 days the fibers may be extracted and processed as linen.

Silage (*sy*-lij) is a fodder for dairy cattle. In making it, shredded corn stalks or alfalfa, clover, and oat plants are put in a silo. Bacteria (*Lactobacillus*) ferment the sugar in the plants and form lactic acid. During the fermentation, oxygen is consumed and carbon dioxide is produced, settling in the silo. This anaerobic condition prevents decay of the plant materials. In the fer-

16-9 These laboratory technicians are examining colonies of bacteria that have been cultured in Petri dishes and test tubes which were placed in an incubator. The instrument pictured here is used to count the number of bacteria colonies per square millimeter of culture. (Ewing Galloway)

mentation of silage, which lasts three weeks to a month, considerable heat is produced. The lactic acid formed is of great value in the milk production of dairy cattle.

The *tobacco* industry uses bacterial action in the curing process. Stalks and leaves of the tobacco plant are harvested and hung in special curing barns where sweating occurs. Bacteria ferment carbohydrates in the moist leaves, producing special flavors.

Bacteria in the dairy industry. In *cheese making,* bacteria are necessary in the formation of lactic acid from milk sugar, or lactose. Lactic acid causes coagulation of the milk solids, including proteins, fats, and insoluble mineral salts.

In making *butter* cream is separated from the other milk solids. After separation the cream is pasteurized to reduce the number of bacteria present. The pasteurized cream is then inoculated with special bacteria that form lactic acid and act on other ingredients of the cream, giving desirable flavors. After a period of bacterial activity the cream is cooled and churned to butter.

Since milk, in addition to being a nutritious food for human beings, is an ideal culture medium for bacteria, great care must be used in maintaining rigid sanitary regulations throughout the dairy industry. Without these regulations, milk and ice cream would become a source of epidemics. ***Pasteurization*** is a method of partial destruction of bacteria in milk as well as in fruit juices, wines, and malt beverages. The principle of pasteurization was discovered by Louis Pasteur and was first used to prevent souring in wines.

Milk is pasteurized by heating it to a temperature of 140–150° F, holding it at this temperature for 30 minutes, then cooling it quickly. About 90 percent of the bacteria present, including most of the pathogens, are killed during the process. Rapid cooling retards the growth of surviving organisms. Thus pasteurization not only reduces the danger of infection from contaminated milk but also delays souring. However, pasteurized milk must be kept refrigerated to reduce bacterial growth and should be covered to avoid introducing additional bacteria from the air.

Food spoilage and preservation. Bacteria are among our chief competitors for food. We cannot even estimate the amount of food lost each year because of spoilage resulting from bacterial action. Carbohydrates ferment easily, protein foods putrefy, and fats and oils become rancid.

Most foods would remain edible many months or even years if bacteria were not present, or if they could not multiply in them. Thus, there are two general methods of preserving foods. One is the destruction of all bacteria present and the sealing of food in an appropriate container. The other involves environmental control. If foods are held in conditions that will not allow bacterial growth and activity, they will not spoil even though bacteria are present in an inactive or dormant condition.

Canning will preserve foods indefinitely if the canning is done properly.

Salt curing destroys bacteria by plasmolyzing cells. This method has been used for centuries in preserving fish and pork and other meats.

Refrigeration, while it does not kill bacteria, slows down the chemical activity of bacterial enzymes. This not only retards growth and multiplication of bacteria but also reduces their chemical activity, which causes food spoilage.

Quick freezing is a far more efficient method of preserving foods that can be frozen solid. At temperatures of 0° to minus 10° or minus 15° F, bacteria cease all activity.

Dehydration involves the removal of water from a food to the point that bacteria cannot grow or secrete enzymes. Active bacterial cells may be killed by dehydration, although endospores may survive. Dehydrated foods are widely used today. They are easily packaged and shipped and require no refrigeration. They must be kept dry, however, or spoilage will occur rapidly. When ready for use they are rehydrated by adding water.

Chemical preservatives, once very widely used, are largely discontinued or forbidden by law today, although some foods, including dried fruits, are still preserved with harmless chemicals.

Radiation may be used much more widely in years to come in the food industries. If meats and other foods are packaged and sealed, then irradiated to kill all organisms present, they will keep indefinitely without the necessity of drying or refrigeration.

Relatives of bacteria – the rickettsiae. The ***rickettsiae*** (rik-*et*-see-ay) are a group of organisms that seem to be midway between the bacteria and the viruses. If we consider viruses to be nonliving or near-living, then the rickettsiae are the smallest living organisms. Rickettsiae are tiny rod-shaped or spherical organisms averaging 0.3 to 0.5 μ in size. They are barely visible under the highest magnifications of the light microscope.

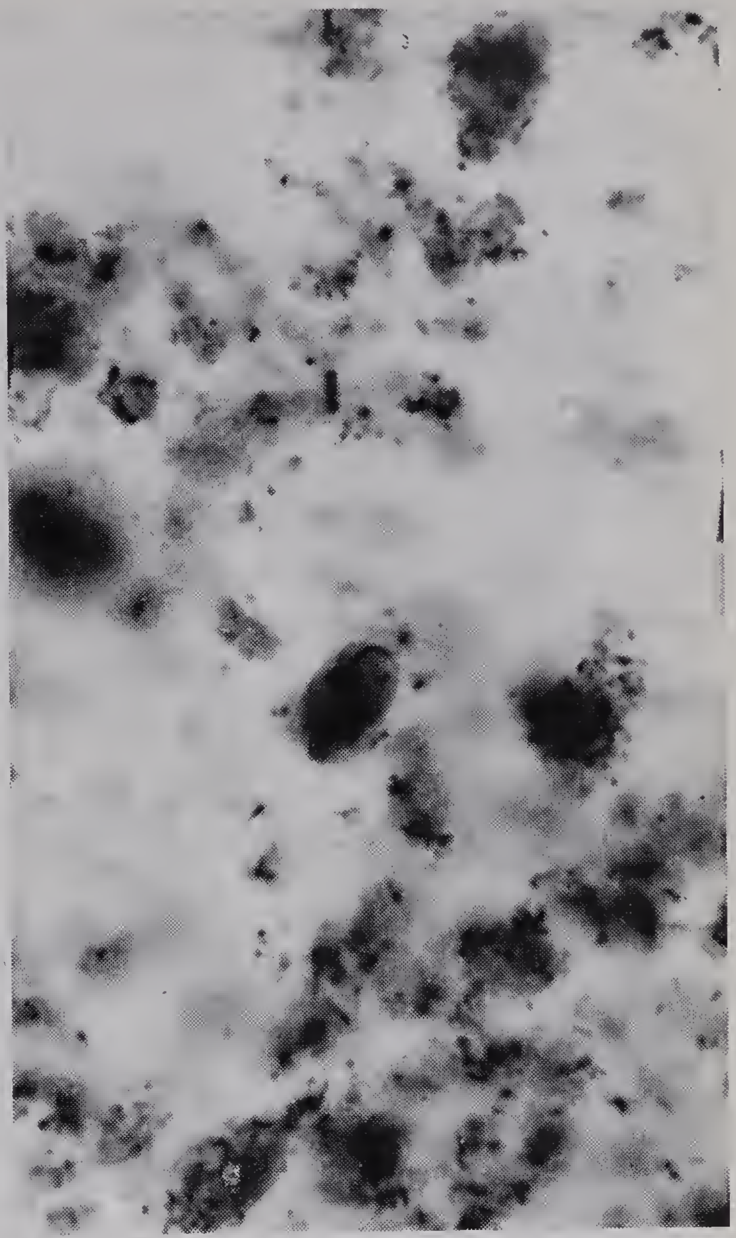
Rickettsiae resemble bacteria in that they are cellular and reproduce by fission. They are similar to viruses in that they can live only in direct contact with a living cell. Thus they must be cultivated in tissue cultures, chick embryos, or in the tissues of animals.

The rickettsiae were discovered in 1909 by Dr. Howard T. Ricketts, for whom they were named. Dr. Ricketts found the first rickettsial organism in the blood of victims of Rocky Mountain spotted fever. He also demonstrated that cattle ticks transmit this rickettsial infection to human beings. It is ironic that Dr. Ricketts died of typhus fever in 1910, a victim of the rickettsial organism he was investigating at the time.

As far as we know, rickettsiae are transmitted only by insects and their relatives, including the human body louse, ticks, and mites. The organisms live in cells of the carrier's intestine but do not cause disease. In the human body, however, they invade cells and cause infection. Those who recover from a rickettsial disease have an immunity to damaging effects of the organisms, although they may remain in the tissues without apparent damage.

In addition to Rocky Mountain spotted fever and typhus fever, rickettsiae cause trench fever and the mysterious Q fever. These infections are similar in producing fever, skin rashes, and dark blotches caused by hemorrhages beneath the skin resulting from damage to the cells lining small blood vessels.

The spirochetes. A group of microorganisms called ***spirochetes*** (*spy*-ro-keets) seem to lie between the bacteria and the more specialized one-celled protists we call protozoans. Many of the spirochetes fall in the size range of bacteria, with cells 3 to 15μ in length and 0.5μ in thickness. However, certain spirochetes reach a length of as much as 500μ. The cells of spirochetes are long and cylindrical. Some are in the form of spirals while others are tight corkscrews. So far as is known, no spirochetes have an organized nucleus. Reproduction is by transverse fission. Endospores are not produced. The cell walls of spirochetes are flexible, permitting the organisms to move through fluids with a characteristic quivering action. All spirochetes were thought to lack flagella until recent studies of certain forms (*Treponema*) [trep-o-*nee*-ma] with the electron microscope revealed threadlike cytoplasmic projections looking like flagella.



16-10 The tiny black bodies shown in this photomicrograph are rickettsiae. They are smaller than bacteria and larger than viruses. (General Biological Supply House, Inc.)

We are most familiar with the spirochetes that live in the human body and cause disease. The best known pathogenic spirochete is the syphilis organism (*Treponema pallidum*), which lives in the blood stream and may invade the nervous system. Spirochetes are spread in discharges from lesions or eruptions in the skin and mucous membranes in early stages of the disease.

IN CONCLUSION

If numbers of an organism are any indication of success, we must admit that bacteria are the most successful. These lowly forms of life are not only the most abundant organisms, but they probably occur higher in the atmosphere, deeper in the seas, and farther in the ground than any other group.

Their requirements vary widely. Some must live in contact with a living host. Others can digest almost any form of organic matter. Still others utilize inorganic compounds and could survive if there were no other forms of life on the earth. Some bacteria have still another great survival advantage. If conditions are not favorable for active life, they merely stop activity.

Having considered both beneficial and harmful activities of bacteria, we now turn to the area of greatest concern about them — the production of infection in the human body. It is in this phase of bacteriology and medicine that some of the greatest chapters in scientific progress have been written.

BIOLOGICALLY SPEAKING

bacillus
Brownian movement
capsule
coccus
endospore
facultative aerobes
facultative anaerobes
flagella
host
obligate aerobes
obligate anaerobes
parasite
pasteurization
pathogenic
rickettsiae
saprophyte
sheath
slime layer
spirillum
spirochetes
true movement

QUESTIONS FOR REVIEW

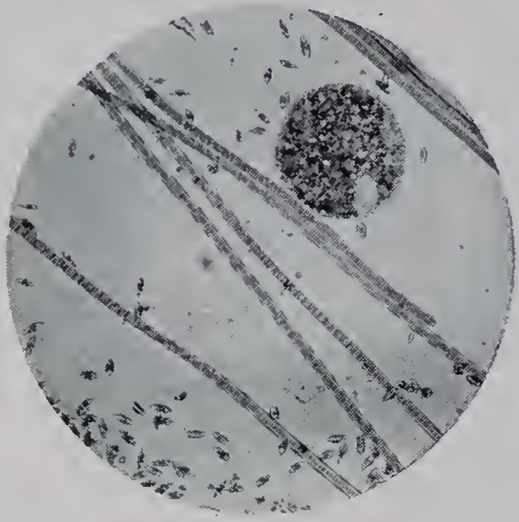
1. What difference did Louis Pasteur find in the population of microorganisms in the two samples of beet juice extract he examined?
2. Explain why bacteria are classified as protists rather than plants in the recent classification of living things.
3. Expressed in microns, what is the average size of bacteria?
4. Classify bacteria into three groups, based on the shape of their cells.
5. Distinguish between a bacterial slime layer and a capsule.
6. What genetic material is present in the genes of bacteria?
7. Describe the structure and function of bacterial flagella.
8. Distinguish between true movement and Brownian movement of bacteria.
9. List four environmental requirements for the growth of bacteria.
10. Distinguish between heterotrophic and autotrophic bacteria.
11. Distinguish between aerobic and anaerobic bacteria.
12. Name several products of the fermentation of glucose by microorganisms.
13. Name two products of true anaerobic respiration.
14. By what method and how rapidly do bacteria multiply under ideal conditions?

15. Why are certain bacillus bacteria more difficult to destroy than other forms of bacteria?
16. List several industrial uses of bacteria.
17. Describe several uses of bacteria in the dairy industry.
18. Explain the slow method of milk pasteurization.
19. List several methods of preserving foods by killing bacterial cells; by controlling the environment and preventing growth and reproduction.
20. How are the rickettsiae transmitted to humans?
21. Name several infections caused by rickettsiae.
22. List several infections caused by spirochetes.

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the composition and organization of genetic materials in a bacterial cell.
2. Discuss several factors that retard the rate of growth and multiplication of bacteria in a culture.
3. Discuss endospore formation in bacilli, including the manner in which spores are formed and the biological importance of the process.
4. Give evidence to support the recent claim that bacteria reproduce sexually. What may be the significance of this type of reproduction in bacteria?
5. Discuss the position of the rickettsiae in relation to bacteria and viruses.
6. Compare bacteria and spirochetes on the basis of structure and activity.

CHAPTER 17



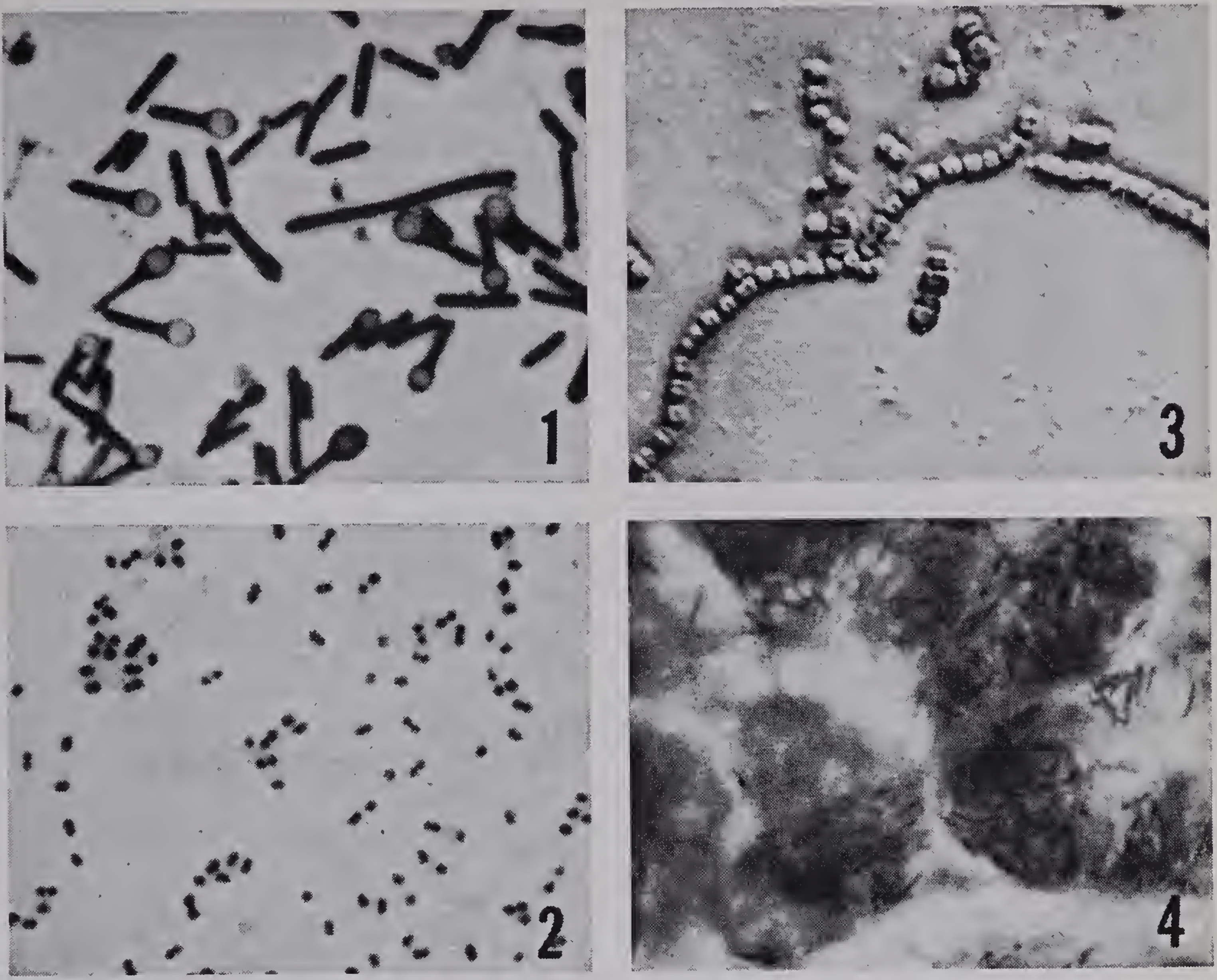
INFECTIOUS DISEASE

Pathogenic organisms. Various kinds of microorganisms are capable of producing infectious disease if they gain access to the body, multiply in the tissues, and cause a host-parasite interaction. We may include as infectious organisms: viruses, rickettsiae, bacteria, spirochetes, yeasts, molds and moldlike organisms, protozoans (animal-like protist organisms), and parasitic worms. We shall limit our discussion of infectious diseases in this chapter to those caused by viruses, bacteria, rickettsiae, and spirochetes.

It is appropriate that we begin our study of infectious disease with the work of an outstanding scientist who made an investigation of an infectious disease during the same period in the 19th century in which Louis Pasteur was conducting his studies in France. Prior to this time the treatment of disease had been based largely on superstition. People had no basis for associating disease with microorganisms. When Pasteur proved that yeasts caused fermentation of beet juice, he also suspected that the rod-shaped organisms he found were responsible for the abnormal souring of the juice. He reasoned that if these organisms could cause such an effect in beet juice, perhaps they could also cause disease in man. This is known as Pasteur's Germ Theory of Disease. Remarkable support for this theory came from a German by the name of Robert Koch.

Robert Koch, the father of bacteriological technique. Robert Koch (kok) [1843–1910] was born in Germany, the son of a poor miner and one of 13 children. His first outstanding contribution to medicine was in the study of anthrax, an epidemic disease of animals often contracted by man. From early times anthrax had spread through sheep, cattle, and other herds in epidemics. In examining organs of animals that died from anthrax, Koch found numerous rod-shaped bacteria swarming in the blood vessels. His next problem was to find out if these organisms caused the disease. He transferred some of the living bacteria into a cut made at the base of the tail of a healthy mouse. The mouse developed anthrax and died. Koch found the same bacteria greatly increased in number in the blood stream of the dead mouse.

Koch was not satisfied until he had actually watched this multiplication. Accordingly he obtained a drop of sterile fluid from the eye of a freshly killed ox and put into the drop a small portion of the spleen of a mouse containing anthrax germs. He patiently watched through his microscope until the germs spread entirely through the drop. He transferred germs from one drop to an-



17-1 The four types of bacteria shown here are all pathogenic. 1. *Clostridium tetani* causes tetanus; note the drumstick appearance of the spore-containing cells. 2. *Diplococcus pneumoniae* causes one form of pneumonia; note that this type is found in pairs. 3. *Streptococcus pyogenes* is responsible for the "strep throat" infection. 4. *Mycobacterium leprae* causes the disease known as leprosy. (General Biological Supply House, Inc.)

other and succeeded in growing them in the complete absence of any mouse spleen or blood. His next step was to try inoculating healthy mice with his laboratory-grown organisms to see if they would produce the disease. The mice died soon after inoculation, and microscopic examination of the blood disclosed the same abundant rod-shaped organisms. Koch thus concluded that anthrax is indeed caused by the bacillus, which provided significant proof of Pasteur's Germ Theory.

Koch's procedure is summarized in four steps called ***Koch's postulates:***

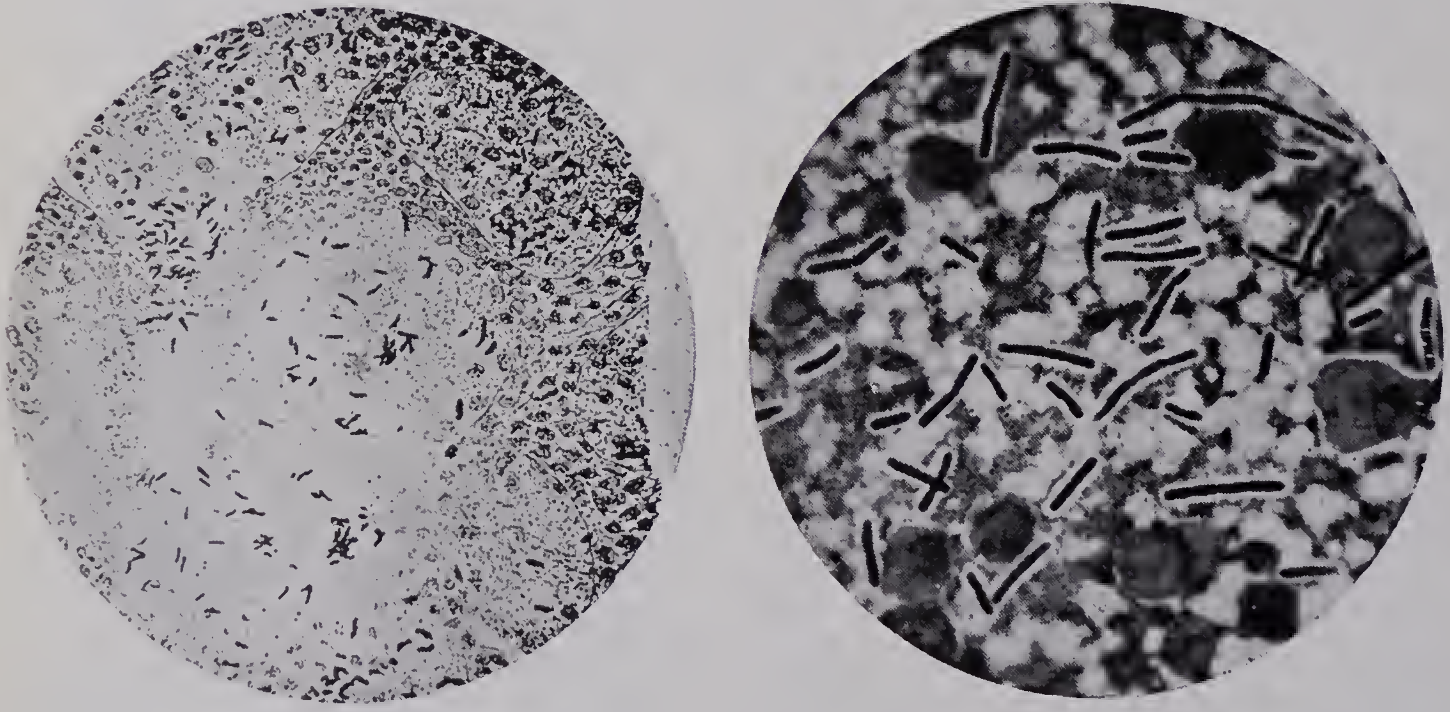
1. Isolate the organism probably causing the disease. (Koch found anthrax organisms in the blood stream of infected animals.)
2. Grow the organisms in laboratory cultures. (Koch used sterile fluid from the eyes of oxen.)
3. Inoculate a healthy animal with the cultured organisms. (Koch inoculated mice with the eye fluid containing germs.)
4. Examine the diseased animal and recover the organisms that produced the disease. (Koch found that the organisms with which he had inoculated the mouse had multiplied enormously in the blood stream.)

The spread of infectious organisms — food-borne infections. Bacteria and other pathogenic organisms may be spread in various ways. Contaminated food is a common agent of infection. Typhoid fever may be spread in food through handling by infected persons. Tuberculosis and various streptococcus infections may travel in milk. Epidemics of undulant fever have been traced to raw milk from cows suffering from a specific infection of cattle.

We must be careful to distinguish between food infection and food poisoning. In *food infection* food is merely the agent in which pathogenic bacteria enter the body. In *food poisoning* bacteria grow in the food and produce poisonous products. The poisons are absorbed into the blood stream from the digestive organs. They act on the body suddenly and within a period of a few minutes to a few hours after eating.

Botulism (*bahch*-u-liz-m) is the most deadly of all food poisoning. Most cases result from home-canned foods, especially string beans, that are eaten before thorough cooking. The botulism organism, a close relative of the deadly tetanus bacterium, thrives in an airtight container. It gets into the food as a spore before canning and multiplies during the period of storage. Poisons are released from the bacteria into the food. Symptoms of botulism usually appear within 12 to 36 hours after the food is eaten. They include double vision, weakness, and paralysis that creeps from the neck region to other parts of the body. Death may result from respiratory failure or heart failure. Mortality occurs in about 65 percent of the cases. Since the poison is destroyed by heat, botulism can be avoided by cooking home-canned vegetables before eating them.

Other ways diseases are spread. Certain bacteria remain alive for days or even weeks in water. Most *water-borne infections* are intestinal and are introduced into water through sewage contamination. Many lakes, streams, and



17-2 Left: Koch cultured this form of the bacterium that causes tuberculosis, using agar with the addition of blood serum. Right: when he examined smears of organs of animals that had died from anthrax, Koch saw a microscopic field similar to this one containing *Bacillus anthracis.* (Left: National Tuberculosis Association; right: General Biological Supply House, Inc.)

shallow wells are dangerously contaminated with the typhoid bacillus, the protozoan that causes dysentery, and other intestinal parasites.

Another very common means of spreading disease is through the droplets given off in sneezes and coughs, and in turn inhaled by others. Diseases spread through *droplet infection* include colds, sinus infections, measles, scarlet fever, and tuberculosis.

Certain diseases produce sores or lesions on the skin. Direct contact with material from these lesions or sores spreads infection. Ringworm of the scalp and impetigo may be spread by such *contact infection*. Chickenpox virus may be transmitted by direct contact or through the air. Diseases spread by direct contact also include syphilis and gonorrhea.

The unbroken skin is an effective barrier against the entrance of bacteria. However, breaks in the skin may result in *wound infections* unless they are cleansed by bleeding and properly treated with antiseptic. Puncture wounds are especially dangerous because of the possibility of tetanus infection. These anaerobic bacteria enter the wound as spores clinging to some object. When the wound heals on the surface, it leaves an airtight cavity ideally suited to the tetanus organism. Various staphylococci commonly infect wounds and produce a characteristic yellow pus. *Streptococcus* wound infections are dangerous and can lead to a fatal general infection.

Certain diseases are spread by *human carriers* who are themselves immune but who harbor the organisms in their bodies. In some diseases, patients who recover carry the organisms in their bodies for weeks or even months. The carrier problem is especially great in typhoid fever.

Insects spread disease in two entirely different ways. Houseflies and roaches carry germs on their feet and body and thus bring them into our homes. Other insects carry infectious organisms internally and transmit them in bites. In this way, typhus is associated with the human body louse, bubonic plague with the rat flea, and African sleeping sickness with the tsetse fly. In these cases the insect serves as a *host* of the infectious organism.

How microorganisms cause disease. Various microorganisms damage the body in several ways. The damage may be mechanical or chemical. Reaction in the host may result in such abnormal conditions as fever, pain, redness, and swelling. It may occur at the place of the infection or in other parts of the body, depending on the kind of pathogen present and the ability of the body to control the infection.

Tissue destruction is a type of damage illustrated by tuberculosis. The organisms usually infect the lungs, although other organs may be affected. As tuberculosis bacteria multiply in the lung tissue, they destroy cells and produce lesions. These allow blood to seep from the capillaries into the air passages, resulting in the hemorrhages characteristic of advanced tuberculosis. Many organisms, including streptococci, destroy blood cells. During meningitis, the membranes covering the brain or spinal cord are attacked by bacteria.

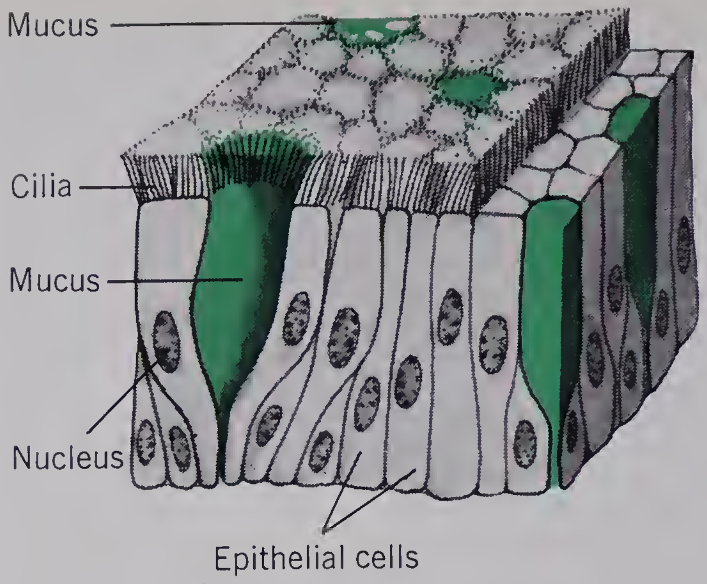
Many bacteria produce chemical substances that are absorbed by the surrounding tissue or are transported through the blood stream with damaging effects. We refer to these poisons as ***exotoxins.*** Such toxins may cause serious damage far from the seat of the infection. For example, tetanus organisms living in a wound in the foot produce toxins that cause paralysis in the upper regions of the body. Other diseases that involve exotoxins include scarlet fever, diphtheria, streptococcus infections, as well as botulism food poisoning.

Endotoxins remain inside the bacterial cells that form them. However, these toxins are released with deadly effect when the bacteria die and disintegrate. Endotoxin diseases include typhoid fever, tuberculosis, cholera, bubonic plague, and dysentery.

Structural defenses against disease. Even though the body is the normal environment of an enormous number of bacteria and other organisms that cause no harm, there is a constant threat of invasion of the tissues by organisms that are capable of causing disease. To prevent such an invasion, the body is provided with many defenses that function at various stages of the attack. These defenses are often compared to lines of soldiers, each equipped with weapons.

The most effective way of avoiding infectious disease is to prevent the organisms from entering the body tissues. This is the function of the structural defenses, composing the first line. *Skin* covers all the external parts of the body and, if unbroken, is bacteria-proof. In addition to being a physical barrier, salts and various fatty acids present in perspiration are believed to destroy some bacteria and make the skin an effective defense against infection. However, natural openings in the skin, such as pores and hair follicles, may allow entry of microorganisms.

The mouth, digestive tract, respiratory passages, and genital tract are lined with *mucous membranes*. These membranes function much as skin does in preventing microorganisms from invading the body tissues. ***Mucus***, secreted by cells of the mucous membranes, is a slimy substance that traps bacteria on the membrane surface. Cells forming the lining of mucous membranes in the respiratory tract are equipped with tiny hairlike projections that sweep bacteria and other foreign materials upward toward the throat. When such particles irritate the mucous membranes of the throat, a cough results and the particles are blown out into the air. Irritation of the membranes of the nasal passages results in sneezing.



17-3 The mucous membrane is one of the first-line defenses. Notice the cilia, which aid in expelling foreign matter.

Tears flow over the eyes continually, not only lubricating them but cleansing them as well. Bacteria and other foreign particles are washed into the tear ducts, which empty into the nasal passages. Recent studies have revealed that both tears and mucus contain enzymes known as ***lysozymes*** (*ly*-so-zymz). These enzymes seem to dissolve the cell walls of many bacteria.

The *acid* secretion of the stomach is another effective structural defense of the body. Great numbers of bacteria enter the stomach in the food we eat. However, few can survive the high content of hydrochloric acid secreted by glands in the stomach wall.

Little is known of the function of *other microorganisms* as a first-line defense. The normal bacterial population of the digestive system seems to interfere with the growth of invading organisms and thus protects the host. The importance of these organisms is demonstrated when drugs destroy much of the normal population of intestinal bacteria. Before they can multiply and re-establish their normal number, other bacteria reproduce in the intestine and cause disease.

Cellular defenses. Once bacteria have passed through the structural defenses of the skin, mucous membranes, and stomach, they are met by a second line, which operates in the body tissues. The principal defenders of this line are ***phagocytic*** (*fag*-o-*sit*-ik) ***cells*** which engulf bacteria and digest them with enzymes, including lysozymes. Among the phagocytic cells are certain of the white corpuscles, or ***leucocytes.*** These cells pass through the walls of capillaries and migrate through tissue fluids to the site of an infection. Here they form a wall around the invading organisms and begin to engulf them. Debris of the battle, consisting of blood serum, digested bacteria, and degenerated leucocytes constitute ***pus.***

During such an infection, which is still local rather than general, the tissues often swell and become inflamed. Redness results from increased flow of blood to the region of the infection to promote healing. Blood vessels enlarge and pour lymph (a clear liquid present in blood) into the tissue spaces. The lymph aids the struggle by carrying bacteria and leucocytes that have engulfed bacteria to lymph nodes where they are filtered out. All of these reactions are part of the inflammation that occurs with body defenses at the cellular level.

Further destruction of microorganisms occurs in the lining of small blood vessels in the liver, spleen, lungs, and bone marrow. Here, special cells composing the *reticuloendothelial system,* capture and engulf bacteria and leucocytes that contain bacteria.

During the struggle between invading microorganisms and the cellular body defenses, the body temperature often rises. This temperature elevation, or *fever,* is a host reaction that reduces or inhibits the growth of many bacteria, activates other body defenses, and increases the rate of body metabolism. Thus fever is a beneficial reaction unless it becomes too high or lasts for too long a period. If this happens, it may damage or destroy cells of the host organism.

The influence of body temperature on the growth of bacteria was demonstrated by Louis Pasteur many years ago. Pasteur was attempting to infect ducks with anthrax bacteria taken from diseased sheep. However, the bacteria would not grow in the blood stream of a duck, in which the body temperature is about 3° C higher than that of a sheep. In other words the normal body temperature of a duck is the equivalent of a three-degree fever in a sheep. However, when he lowered the body temperature of a duck by immersing its feet in ice water, the anthrax bacteria started growing and produced the infection.

Chemical defenses. The body defenses we have described so far have been nonspecific in that they act on any invading bacteria. We now reach the third line of body defenses, which includes various specific ***antibodies*** against disease organisms and their products. Bacteria, as well as their toxins, are protein materials and as such are foreign to the host organism. We refer to such proteins as ***antigens.*** They stimulate the production of specific antibodies that combine with the antigenic material in the blood.

Investigations have shown that antibodies are protein molecules. They are believed to come from the lymph nodes and spleen, from which they enter the blood and lymph. Antibodies against disease are formed *only* in the presence of specific bacteria or bacterial products in the body. Their production begins within a few hours after introduction of antigens in the form of viruses or bacteria or release of bacterial products. Within a few days antibodies enter the blood stream and continue to increase in quantity for three or four weeks. This period usually marks the highest level of antibody production. Antibodies may remain in the blood stream for many weeks or even years. The level of a specific antibody in the blood may decline slowly. A second exposure to the antigen involved speeds up production in the lymph nodes and spleen and raises the antibody level rapidly.

Various antibodies act in interesting ways. *Antitoxins* combine with exotoxins formed by organisms such as diphtheria, scarlet fever, and tetanus. These extremely poisonous bacterial secretions are neutralized when they are joined to specific antitoxins. *Agglutinins* are antibodies which cause certain bacteria to clump together, or agglutinate. In such masses they are more easily destroyed by phagocytic cells. *Cytolysins*, also referred to as bacteriolysins, are antibodies which cause certain bacteria to dissolve. *Precipitins* are little understood antibodies which cause bacteria to settle out in the blood. This action aids in filtering them out in the lymph nodes, spleen, and other organs. *Opsonins* are believed to combine with certain substances in bacterial cell walls and prepare them for ingestion by phagocytic cells.

Immunity against disease. We refer to resistance of the body against infections as *immunity*. It may be present at birth, which is the form called *natural* immunity, or it may be *acquired* during the lifetime of the individual.

For the most part, man has a natural immunity to animal diseases because conditions in the human body are not suitable for the growth and activity of these infectious organisms. This type of immunity, found in all people, is often called *species immunity*. However, there are several notable exceptions to species immunity. Tuberculosis and undulant fever may be transmitted to humans in milk from cattle. Anthrax may be spread by contact with lesions in the skin of infected sheep, cattle, horses, and other animals. Tularemia is spread by infected rabbits, while psittacosis may be contracted from infected parrots and parakeets.

Acquired immunity may be *active* or *passive*, depending on the way in which it is established. Active immunity may be acquired *naturally* by recovering from certain infectious diseases, including diphtheria, scarlet fever, measles, and mumps. During the infection the body produces specific antibodies against the pathogenic organisms or their products. This antibody normally continues after recovery, resulting in permanent active immunity. Active immunity may be acquired *artificially* by using biological preparations containing dead or weakened pathogenic organisms or their products. In this way, the body is stimulated to form its own antibodies without actually having the disease.

Passive immunity is acquired artificially by injecting antibodies which have been produced in other individuals or in animals. This transfer of antibodies, while it provides immediate protection against an infection, is only temporary, lasting from a few weeks to several months in most cases.

Our knowledge of immunity and the use of immune products in dealing with infectious diseases is an important part of medicine. This chapter of medical achievement we refer to as immune therapy represents the knowledge contributed by many great scientists in a series of exciting discoveries of the past two centuries. All of us have benefited from the contributions they made.

Edward Jenner — country doctor. It was during one of the most dreadful smallpox epidemics in England that Edward Jenner, a country doctor, made a discovery that was to alter the course of history. Epidemics took their greatest toll in cities. Jenner noticed that the disease seldom struck people who lived in rural areas and worked around cattle. Most farmers and dairy workers had contracted cowpox and had recovered with nothing more serious than a pustule which left a scar. Were they immune to smallpox? If so, why not vaccinate people with cowpox to protect them from smallpox?

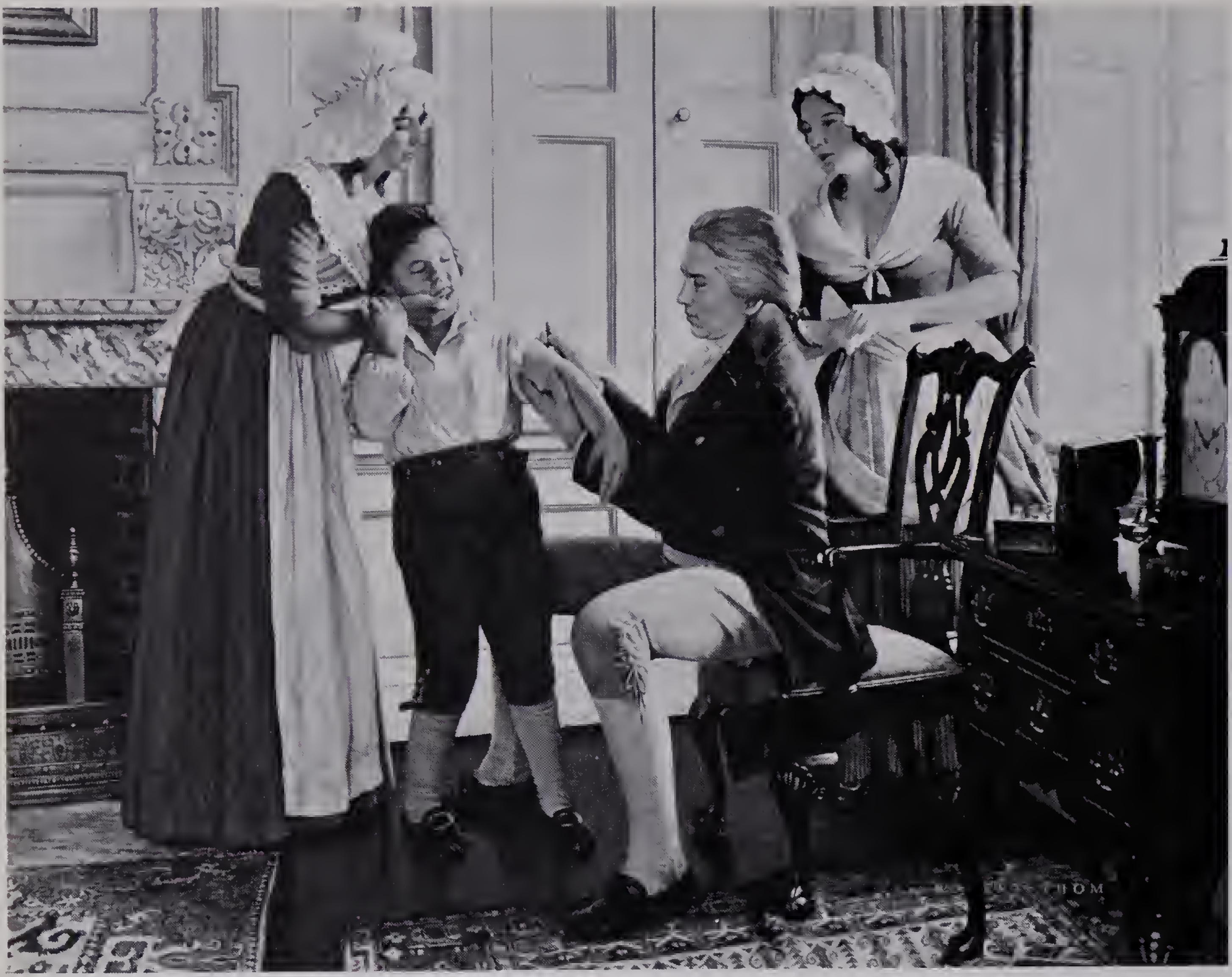
The first vaccination. On May 14, 1796, Dr. Jenner had a chance to test his vaccination theory. His patient was James Phipps, a healthy boy about eight years old. James's mother, with great confidence in Dr. Jenner, allowed her son to be used in the test with the hope that he could be spared the danger of smallpox. Dr. Jenner took his young patient to a dairy maid, Sarah Nelmes, who had a cowpox pustule on her hand resulting from an infection from one of her master's cows. Dr. Jenner made two shallow cuts about an inch long on James Phipps's arm and inoculated them with matter taken from the cowpox sore. A pustule developed on the boy's arm, formed a scab and healed, leaving only a scar. Was James Phipps now immune to smallpox? There was only one way to find out. He must be inoculated with smallpox.

In July of the same year Dr. Jenner deliberately inoculated James with matter from a smallpox pustule. During the next two weeks the doctor watched his patient anxiously for signs of smallpox. They did not appear. Several months later he repeated the inoculation. Again, the disease did not develop. The vaccination was successful. James Phipps was definitely immune to smallpox!

Following this famous experiment Dr. Jenner wrote a paper explaining his method of vaccination. At first the doctors were hostile and would not listen to such a ridiculous procedure. Many townspeople even organized anti-vaccination campaigns. Gradually, however, the doctors and their patients accepted vaccination, and smallpox epidemics were eliminated.

Pasteur's famous immunization experiment. About 80 years after Dr. Jenner vaccinated James Phipps, Louis Pasteur conducted his famous immunization experiments. Previous to these experiments Pasteur had made a vaccine containing the weakened bacteria of chicken cholera. He found that he could inject the vaccine into healthy chickens and produce active immunity against the disease. This led him to try a similar procedure against anthrax at about the same time Robert Koch was conducting his famous work on the disease.

Pasteur made an anthrax vaccine from weakened bacteria taken from the blood of infected animals. He claimed



17-4 James Phipps receives the first vaccination from Dr. Edward Jenner. (© 1960, Parke, Davis & Co.)

this vaccine would immunize animals against the disease. Scientists challenged him to prove his theory. This challenge was the opportunity he had waited for. He selected 48 healthy animals (mostly sheep) and divided them into two groups — an experimental group and a control group. He gave the animals in one group injections containing five drops of anthrax vaccine. Twelve days later he gave the same animals a second injection of a vaccine. Fourteen days later he gave all 48 animals an injection of living anthrax bacteria. Two days later the scientists met at the pens to laugh at Pasteur. Imagine their amazement to find all Pasteur's immunized animals alive and healthy, and all the untreated animals dead or dying of anthrax. This famous experiment was an important milestone in the conquest of disease.

Pasteur's experimentation with rabies. During the latter years of his life, Pasteur turned his genius to experimentation with one of the most dreadful of all diseases, rabies, or hydrophobia. We know today that rabies is caused by a virus. Pasteur, of course, did not know of the existence of viruses. But for the sake of clarity we shall use the term in explaining his work with the disease. This disease was common among dogs, wolves, and other animals during his time. If the virus was transmitted to a human being by a bite, the victim was certain to suffer an agonizing death after an incubation period of a few weeks to six months or more. During this time the virus slowly destroyed brain and spinal cord tissue.

The restlessness, convulsions, great thirst, and throat paralysis that climaxed a rabies infection led Pasteur to believe that the infection centered in the brain. However, microscopic examination of the brain tissue of an animal victim did not reveal any microorganisms. We can understand why today, for the rabies virus is invisible under the ordinary microscope.

Pasteur found that he could transmit rabies by injecting infected brain tissue from a rabid dog to a healthy one. He repeated the inoculations with rabbits and discovered that the virus gained strength as it was passed from one animal to another. However, if spinal cord tissue taken from a dog or rabbit was dried for 14 days, the virus lost its strength and could no longer produce the infection. Virus 13 days old was only slightly stronger. The discovery that the virus weakened with drying and aging led to experiments to find out if rabies immunity could be produced. Pasteur injected 14-day-old brain tissue from a rabid animal into a healthy dog, then followed this injection with 13-day-old material.

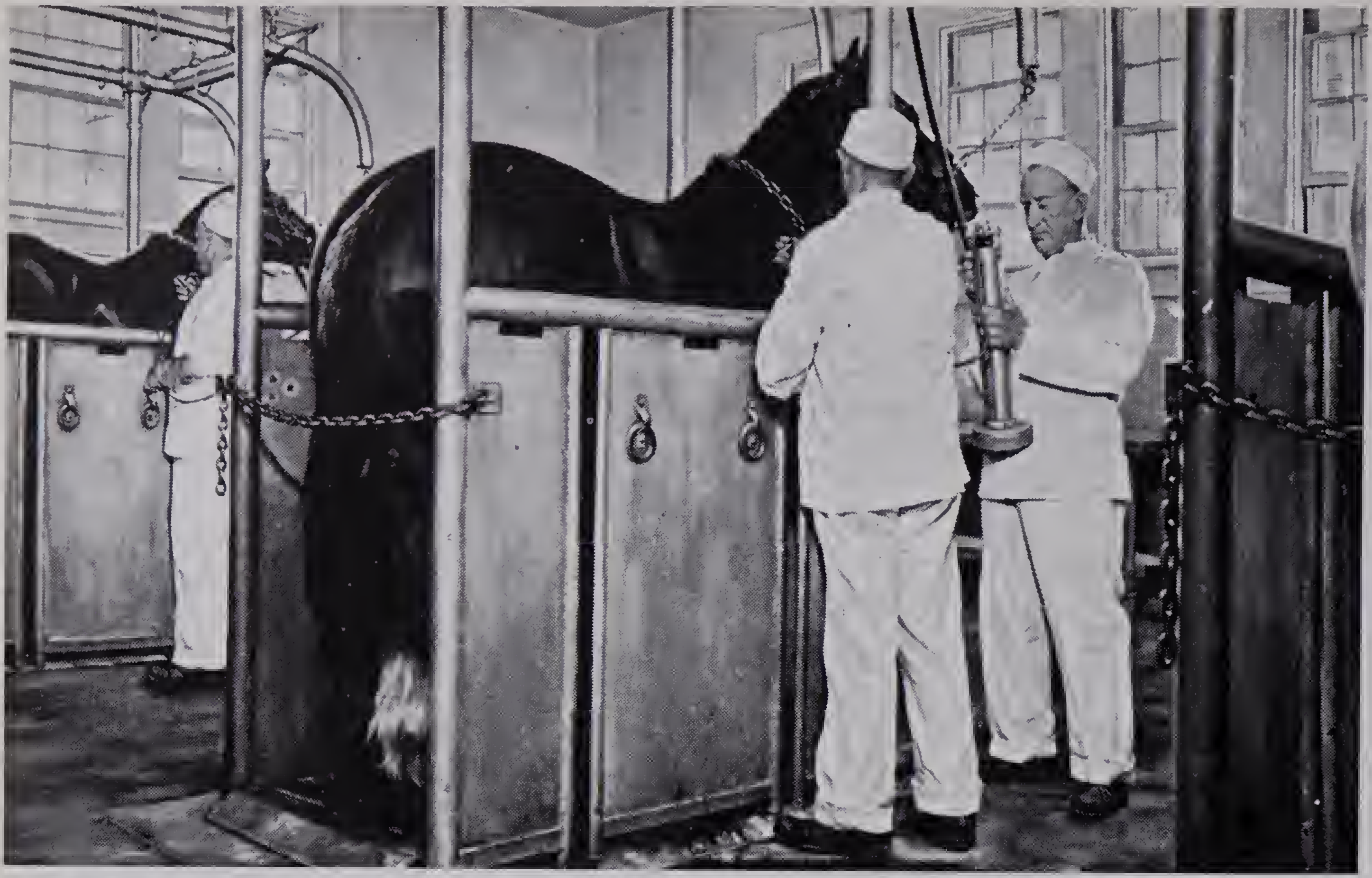
The injections were continued day after day until the dog was given an injection of full-strength virus in the 14th injection. The animal suffered no ill effects. The series of injections with material of increasing strength had produced immunity to rabies. The question now was whether he dare try the series of injections in human victims. A decision was forced on Pasteur a short time later.

Pasteur's treatment of rabies. On July 6, 1885, a frantic mother brought her son to Pasteur's laboratory, pleading that he use any method to save her boy's life. The boy had been attacked by a rabid dog two days before they reached Pasteur's laboratory. Pasteur had no time to lose and no choice except to give the boy the treatment that had worked on dogs. The physicians and laboratory assistants he consulted agreed with his decision. On the evening of this important day, the boy was given an injection of rabbit-grown virus that had aged 12 days. Injections were repeated each day, using successively fresher virus. On the 12th day he received full-strength virus. After several weeks of observation he was sent home, the first human being immunized against rabies.

This series of injections, known as the Pasteur treatment, is used today to immunize victims of bites by rabid dogs. The virus used in making the vaccine was once grown in rabbits. However, a recent method of growing the virus in the embryos of developing duck eggs has proved more satisfactory because there is no danger of serious body reaction to the substances present in nerve tissue of the rabbit.

The conquest of diphtheria. From the earliest times diphtheria was one of the worst epidemic killers, especially among children. The effects of diphtheria on the body are twofold. The germs grow in a thick, grayish-white membrane on the back wall of the throat. As the membrane spreads, it may block the glottis opening and cause death by strangulation. In addition, toxins are given off by the living bacteria and are absorbed through the infected tissues into the blood. They often cause severe damage to the heart, nervous system, and other organs.

The conquest of diphtheria some 50 years ago involved the work of several scientists. One found the rod-shaped



17-5 Diphtheria antitoxin is prepared by first injecting quantities of diphtheria toxin into the blood of a horse. After removal of blood from the external jugular vein in the neck, it is processed to remove antitoxins from the rest of the blood substances. (© 1957, Parke, Davis & Co.)

bacteria growing in the throats of patients with diphtheria. Another worker cultured the bacteria and developed a stain used in microscopic study of the organisms. However, much of the credit for the conquest of this disease belongs to Emil von Behring (fahn *ber*-ing), a German bacteriologist.

Von Behring was puzzled by the fact that, even though diphtheria organisms remained in the throat, the effects of the disease appeared in distant organs. When bacteria were grown in culture media, they produced a ***toxin*** which, when injected into guinea pigs, produced the symptoms of diphtheria even though no germs were present.

While conducting such experiments with diphtheria toxin, von Behring discovered that guinea pigs and rabbits could be used only once. They developed immunity to the disease. Could this immunity be transferred to animals that had never been given doses of toxin? In an effort to answer this question, von Behring took a fraction of the blood from immune animals and injected it into other animals. They too were made immune to diphtheria toxin. Von Behring named the substance that had produced immunity ***antitoxin.***

Sheep were used first in the production of diphtheria antitoxin. After extensive testing of the antitoxin in guinea pigs, it was first used with great success in the Children's Hospital in Berlin. Von Behring found that immunity resulting from injections of sheep antitoxin lasted only a few weeks. Apparently the antitoxin is destroyed slowly in the human blood stream. If children could be made to produce their own antitoxin, immunity would be as lasting as though they had recovered from diphtheria. To give diphtheria toxin would be as dangerous as inoculating them with the disease itself. Von Behring reasoned that a mixture of toxin and antitoxin might be safe to use. World War I prevented von Behring from finishing his work on such a ***toxin-antitoxin.*** However, it was completed in the United States by Dr. William H. Park and other workers. Toxin-antitoxin was used in producing immunity to diphtheria until it was discovered that some people have a serious reaction to it. This problem has been solved by using a ***toxoid,*** which is a toxin that has been weakened with heat and chemicals to make it safe for injection in human tissues.

Immune therapy summarized. The work of Jenner, Pasteur, and von Behring represents two different ways in which artificial immunity may be produced. Jenner was the first to use what is now known generally as a ***vaccine,*** from the Latin word *vacca,* meaning cow. Like Jenner's vaccine, all vaccines are preparations of the pathogenic organisms, which stimulate the victim to produce antibodies against the disease. A vaccine may be made of weakened or killed pathogens or their products. The Salk vaccine, for example, is made from polio virus weakened by treatment with formaldehyde.

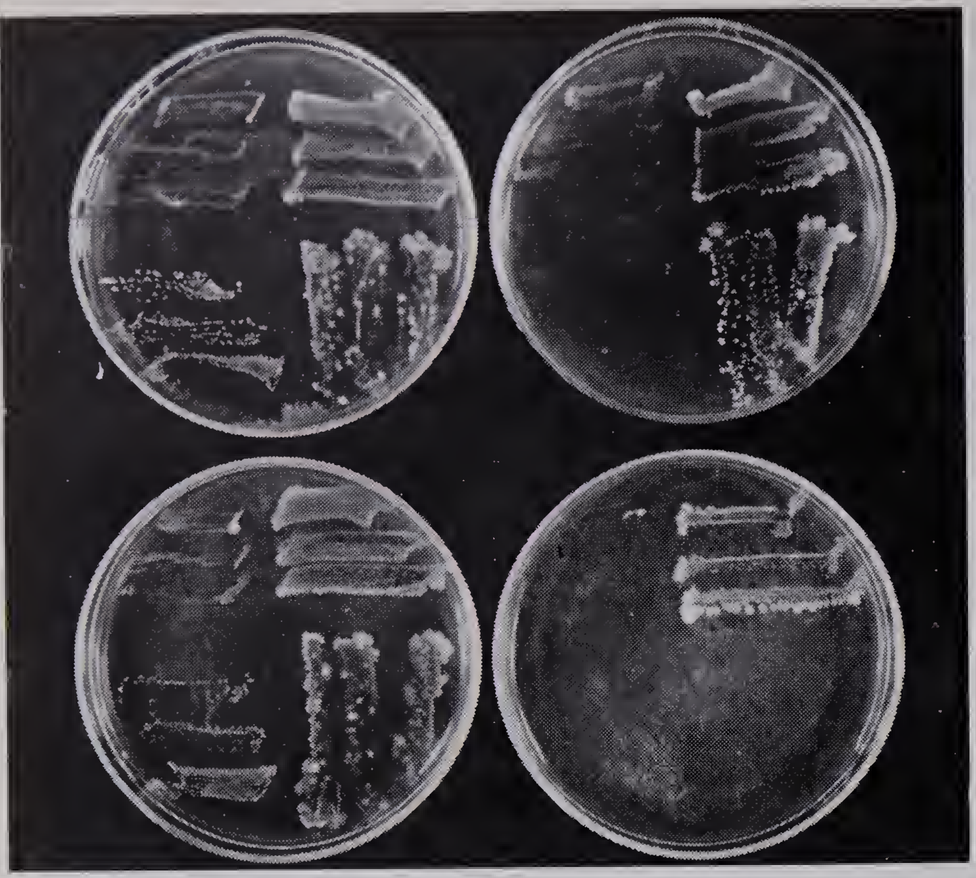
Von Behring's work with diphtheria illustrates the second kind of immune therapy, which involves injecting the victim with antibodies specific to the disease. These antibodies are contained in ***serum,*** which is a blood fraction. The gamma globulin that can be given to produce temporary immunity to polio is administered in a serum. Serum usually comes from the blood of an animal that has been inoculated with a disease and has produced antibodies against it. The diphtheria toxin-antitoxin is a preparation of horse serum. A serum is used to reinforce the body's production of antibodies during an infection. It is also used to give an immediate immunity to someone who has been exposed to a disease.

Chemotherapy. The conquest of disease is not a war of biology alone, for chemistry plays a very significant part. Chemotherapy is a recent field in which specific chemicals are used to destroy germs. It is of great importance because it assists the natural body defenses.

The development of chemotherapy is associated with the work of a brilliant German chemist, Paul Ehrlich (*er*-lik), in connection with his long search for a cure for syphilis. Ehrlich spent many years attempting to discover a drug that would kill the organisms in the blood stream without damaging the blood or other parts of the body. After 605 unsuccessful attempts he finally succeeded. His 606th drug was an arsenic compound called *salvarsan.* It was used in treating syphilis many years before penicillin was discovered.

Other scientists began experimenting with chemicals in the treatment of disease. In 1932 Dr. Gerhard Domagk (*doh*-mag), another German scientist, discovered that a red dye called *prontosil* had remarkable germ-killing powers. Soon after his discovery of prontosil, he tried it on his own daughter, who was dying of a streptococcic infection that had progressed beyond medical control. It proved to be effective in halting the infection and saved the child's life.

Further investigations on prontosil proved that only a part of the drug had germ-killing powers. This part was isolated and called *sulfanilamide* (sul-fah-*nil*-a-myd). It was the first of an im-



17-6 Each of these Petri dishes contains the same four strains of bacteria, arranged in the same order. An antibiotic has been added to each culture, using an increasingly potent dose on the respective dishes. The bacteria in the upper right-hand corner of each dish are least inhibited by the antibiotic. Which strain is most easily inhibited? (Society of American Bacteriologists)

portant family known as the sulfa drugs. There are many different ones now, and they are used in the treatment of certain infectious diseases. These drugs should be taken only on the advice and recommendation of a physician. They are not cure-alls and may be dangerous.

Antibiotic therapy. The chemical substances called ***antibiotics*** are now commonly used in the treatment of disease. Antibiotics are products of living organisms. In this respect they are different from the drugs used in chemotherapy. We can sum up the use of antibiotics by saying, "Bugs produce drugs that kill bugs," for our supply of these substances comes from bacteria, molds, and moldlike organisms.

The wonder drug of World War II, *penicillin,* was the first of the antibiotics. It was discovered accidentally by Sir Alexander Fleming, a British bacteriologist, in 1929. Fleming was working with staphylococcus bacteria in a London hospital. While examining plate cultures of staphylococci, he noticed that several of them contained fluffy masses of mold, and that the mold was stopping the growth of the bacteria. Later the mold colonies turned dark green and were identified as *Penicillium notatum,* a relative of the mold found on oranges, and its antibacterial secretion was called penicillin. Since the mold and the staphylococci were competing for the same food supply, it seemed that the secretion of the mold was an adaptation that destroyed the competition.

In the opening days of World War II, Dr. Howard Florey and a group of Oxford workers began a search for antibacterial substances that would be useful in combating wound infections. Their attention turned to Fleming's work and, in cooperation with him, penicillin was developed and thoroughly tested. The result of this work is history.

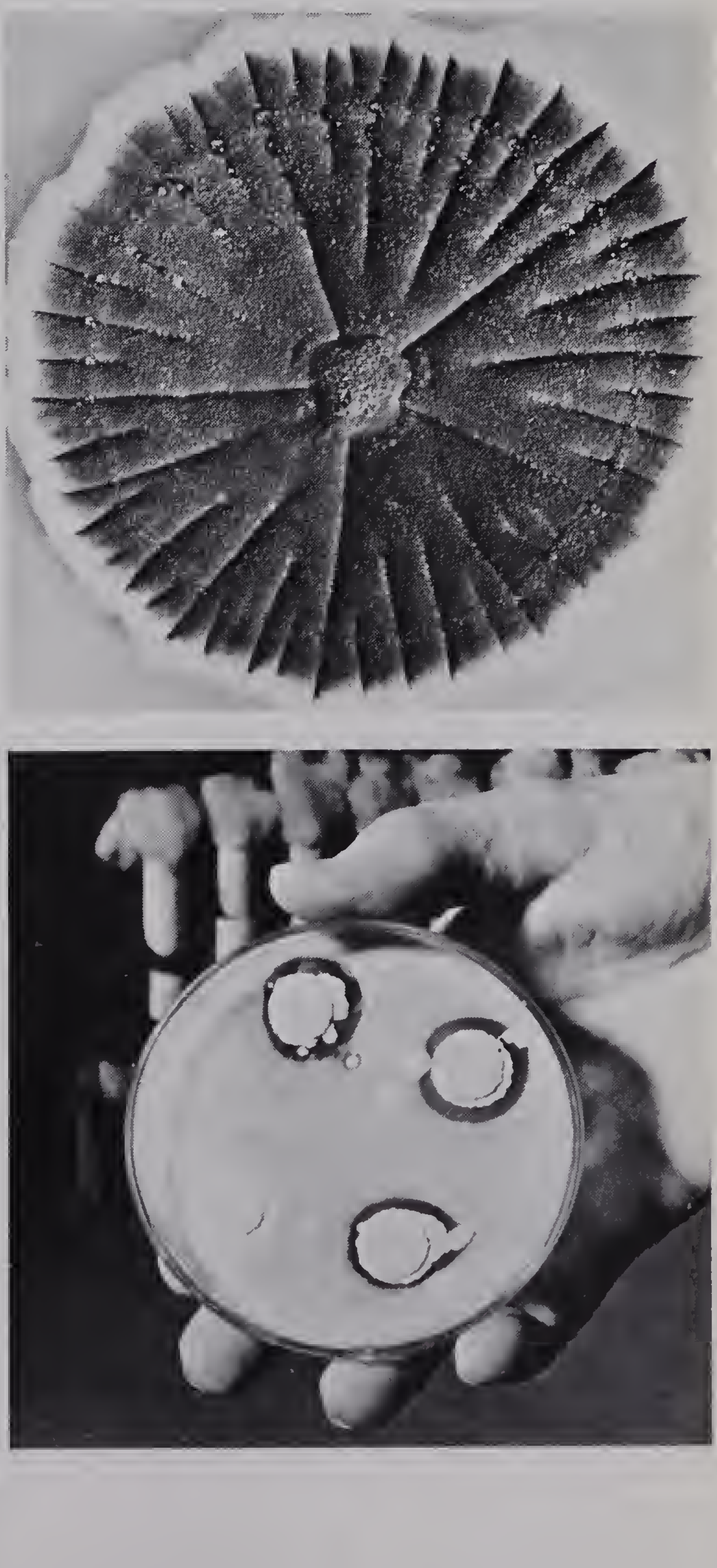
Today a penicillin ten times as powerful as Fleming's is available in unlimited quantity and at low cost. Mutant strains of *Penicillium notatum,* produced by exposure to X rays, yield far more penicillin than earlier strains. Biological companies have even produced penicillin synthetically. It is given effectively in large doses by injection with a slowly absorbed procaine salt. It can be taken by mouth in tablet form and inhaled into the nasal passages in powder form. Ointments are available for use locally and in the eyes. However, it should *never be used in any form unless recommended by a physician.*

Streptomycin. Dr. Selman Waksman became interested in the soil and its relation to life when he was a boy in Europe. Later he came to the United States and enrolled in Rutgers University. His interest in soil led him to the New Jersey Agricultural Experiment Station at Rutgers. While still a student, Waksman discovered a soil organism which he named *Streptomyces griseus.*

After graduate study Waksman returned to Rutgers as a member of the faculty. With the aid of students he continued the investigation of soil organisms. Together they studied the problem of the disappearance of disease organisms when the body of a diseased animal is buried, and found that products of soil organisms destroyed the pathogens. After years of testing the effect of soil organisms on various pathogens, *streptomycin,* an antibiotic substance produced by *Streptomyces griseus,* was discovered.

Streptomycin proved to be an effective drug against tuberculosis. In addition, it is partially effective against whooping cough, some forms of pneumonia, dysentery, gonorrhea, and syphilis. The streptomycin industry grew rapidly, and this valuable antibiotic took its place with penicillin.

Other antibiotics. Today many new antibiotics have been added. Among these is *terramycin* (tair-uh-*mys*-in), which promises to be of great value because of its wide range of effectiveness and low toxicity in the body. *Erythromycin* (eh-rith-roh-*mys*-in), one of the more recent antibiotics, is similar in ac-



17-7 The top photograph shows a culture of the mold *Penicillium notatum* growing on a Petri dish culture. The antibiotic, penicillin, is obtained from this mold as well as from other species of the same genus. In the bottom photograph, disks have been soaked in four different strains of penicillin and placed in a bacterial culture. Notice that the strain at the lower left has no inhibiting action on these particular bacteria. (Chas. Pfizer and Co.)

tion to penicillin. This substance is especially valuable in dealing with organisms that have a resistance to penicillin. *Tetracycline* (te-tra-*sy*-kleen), another recent one, is produced under a variety of commercial names. The search for new and better antibiotics continues. An ideal antibiotic has a broad spectrum, or range, of organisms against which it is effective. It must also destroy pathogenic organisms without injury to the body tissues or disturbance of body functions.

One reason for limiting the use of antibiotics is because they sometimes produce side effects. A severe allergic reaction to penicillin is not uncommon. Other antibiotics may create digestive disturbances. This is often the result of destruction of most of the organisms that normally grow in the intestine when the antibiotic is taken by mouth.

A second and perhaps most important reason for caution involves the process of adaptation and natural selection. The bacteria causing a disease vary somewhat in their characteristics, like members of any species. When an antibiotic is used, some of the population of pathogenic bacteria may have adaptations that allow them to resist the effects. Repeated use of the antibiotic may kill off the other, more susceptible bacteria while allowing the resistant one to multiply and produce new strains in a short time. This is becoming more and more of a medical problem. For example, penicillin was very effective against staphylococci for many years. Then resistant strains became more and more abundant until today they are a great problem in hospitals.

IN CONCLUSION

You might think of your body as a fort, with defenses set up against invading microorganisms. Microbe enemies are always with us. Normally, we hold them in check. But when they overcome our defenses and multiply in our tissues, an infectious disease may develop rapidly.

By understanding the nature of infectious disease — the host-parasite relationship and interaction — we may reinforce our natural body defenses. Biological products are available to establish immunity before an infection develops or to bolster the natural antibodies in dealing with infection. Chemotherapeutic and antibiotic drugs of many kinds are valuable weapons in the battle against infection.

BIOLOGICALLY SPEAKING

antibiotic
antibody
antigen
antitoxin
botulism
endotoxin
exotoxin
immunity
Koch's postulates
leucocyte
lysozyme
mucus
phagocytic cell
pus
reticulo-endothelial system
serum
tissue destruction
toxin-antitoxin
toxoid
vaccine

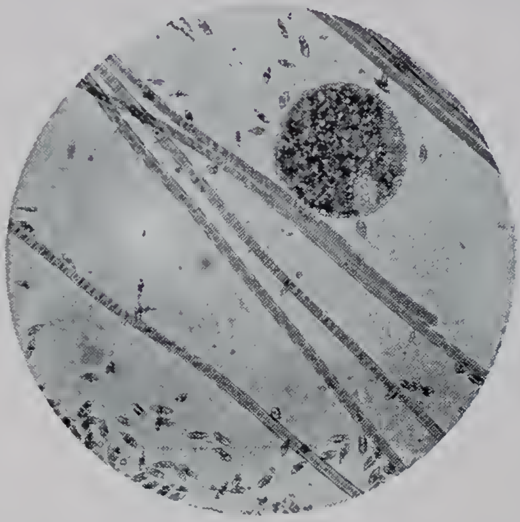
QUESTIONS FOR REVIEW

1. List eight microorganisms that may produce an infection in the human body.
2. List the Koch postulates and describe each as a step in the investigation of an unknown disease.
3. Distinguish between food infection and food poisoning.
4. Name several diseases spread by droplet infection.
5. List several diseases spread by direct contact.
6. Name a disease associated with human carriers.
7. Distinguish between an exotoxin and an endotoxin.
8. List the principal structural defenses of the body.
9. In what way do lysozymes function in body defenses?
10. Give two examples of phagocytic cells that function at the level of cellular defense.
11. In what way is fever an important body defense?
12. What is an antigen?
13. Distinguish between natural and artificial immunity.
14. Distinguish between a toxin, antitoxin, toxin-antitoxin, and toxoid from the standpoint of origin and action.
15. What medical contributions were made by Ehrlich and Domagk?
16. How are antibiotics different from other drugs used in chemotherapy?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the scientific contribution of Robert Koch in his investigation of anthrax.
2. Discuss the specific and nonspecific body defenses.
3. Discuss the contribution of Edward Jenner to the rise of immune therapy.
4. What significant contribution did Emil von Behring make to our knowledge of immunity?
5. Discuss the principle involved in the Pasteur treatment for rabies.
6. Discuss the way in which natural selection produces bacteria resistant to antibiotics.

CHAPTER 18



THE PROTOZOANS

The protozoans – four phyla of related protists. Before biologists began to recognize the need for a kingdom Protista, they classified in a single phylum of the animal kingdom a large number of related one-celled organisms having specialized cell organelles. *Protozoa,* the name given to this phylum, means, literally, "first animals." The protozoans were in turn divided into four classes, according to their means of locomotion. Since many of these organisms are not distinctly animal, today most biologists classify them as protists and consider the classes to be four separate phyla of that kingdom. See the Appendix for the names of these phyla and some examples. Though only a few examples are given in the Appendix, there are thousands of species of protozoans. While some biologists estimate 15,000, others believe that there are as many as 100,000 protozoan species.

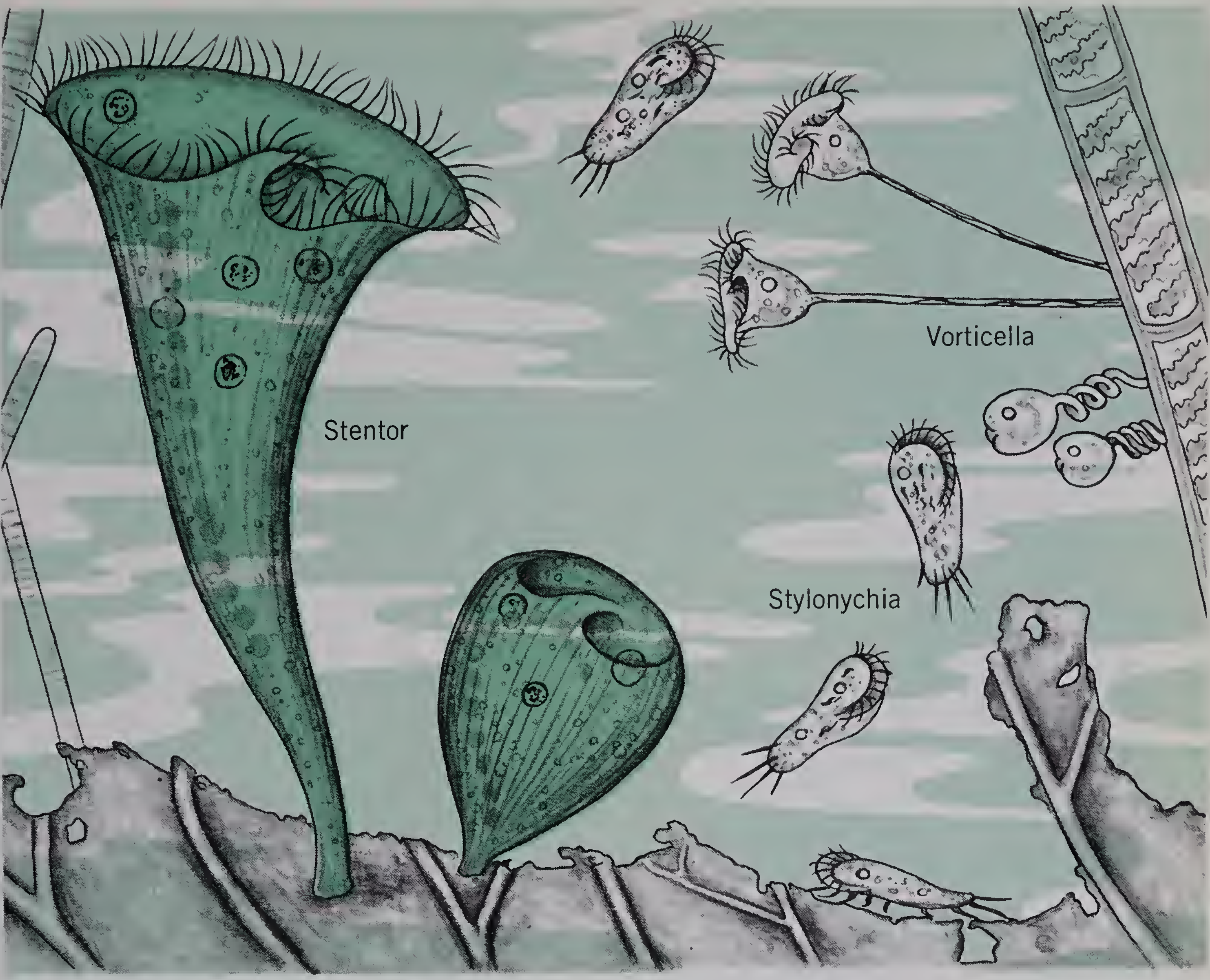
The protozoans are fascinating to study. Some have mouths and gullets, while others merely flow around their food. Some dart thither and yon by means of tiny hairlike projections that act like oars. Others wave flagella in front of them and thus project themselves forward and backward. Some even sting their victims with poison threads. The highly specialized organelles of the protozoans enable them to live efficiently as single cells, carrying on all the life processes in a microscopic universe.

A mass of living jelly. The genus *Ameba* includes several species of interesting protozoans. An ameba might be described as "animated jelly." On first seeing it you might mistake it for a nonliving particle. But this tiny blob of grayish jelly moves of its own accord, takes in food, and performs all the other life processes.

These protozoans may be collected by taking slime from the bottom of streams and ponds and from the surface of the leaves of aquatic plants. The experience of collecting samples and searching through the microscopic world for an ameba is a rewarding one.

Under the microscope the ameba appears as an irregular mass of jellylike protoplasm surrounded by a thin membrane (Fig. 18–2). If you find an active animal, you will notice that the cytoplasm has a constant flowing motion. This streaming cytoplasm presses against the cell membrane and produces numerous projections called *false feet,* or ***pseudopodia*** (soo-doh-*poh*-dee-uh). This type of locomotion is called ***ameboid movement.*** It is responsible for the classification of the ameba in the protist phylum **Sarcodina.**

A closer look at the ameba will show that the cytoplasm is of two different types: a clear, watery ***ectoplasm*** is found next to the cell membrane; the ***endoplasm,*** found inside the ectoplasm,

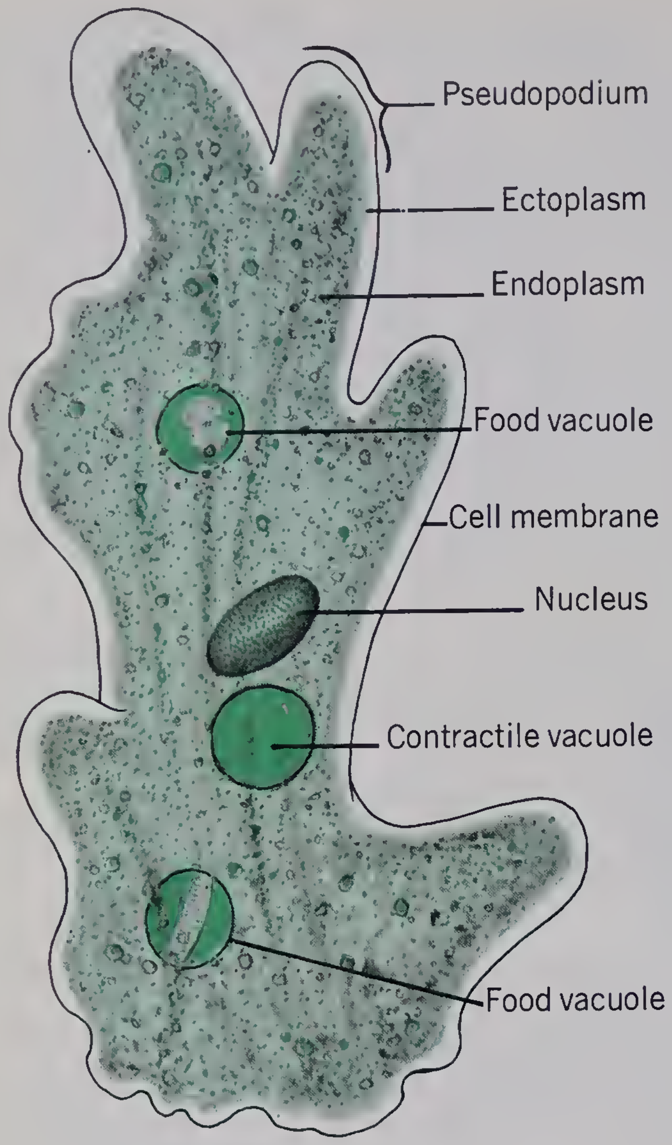


18-1 Many of these interesting ciliated protozoans may perhaps be found in a pond or stream near your home or school.

is denser and resembles gray jelly with pepper sprinkled through it. The nucleus can be seen as a bronze-colored mass that changes its position with the flowing cytoplasm.

How the ameba gets food. When an ameba comes in contact with a one-celled green alga, a small diatom, or another protozoan, it extends pseudopodia, which entirely surround the food. Part of the membrane of the ameba now becomes the lining of a ***food vacuole*** inside the cytoplasm (Fig. 18–2). Digestion is accomplished by enzymes, formed by the cytoplasm, which pass into the vacuole and act on the food substances. Digested food is absorbed by the cytoplasm and may then be oxidized to release energy, or assimilated to form additional protoplasm. Undigested particles remain in the vacuole and pass out of the cell at any point in the membrane.

The oxygen necessary to maintain the life of these protists diffuses through the cell membrane. Most of the carbon dioxide and soluble wastes pass out through the cell membrane. However, with the intake of food, and by the process of osmosis, much useless water comes into the body of the ameba. If the ameba did not have a method of ridding itself of this water, it would swell up like a balloon and burst. As the excess water accumulates it forms a ***contractile vacuole.*** When this vacuole reaches maximum size, it discharges the water through a temporary break in the



18-2 The structure of an ameba. As this protist moves by its pseudopodia, it assumes many different shapes.

cell membrane. In this way the organism maintains a constant or nearly constant internal water concentration.

Sensitivity in the ameba. The response of the ameba to conditions around it is a good example of the sensitivity of protoplasm. It has no eyes, yet it is sensitive to light and seeks areas of darkness or dim light. It has no nerve endings such as we associate with the sense of touch, yet it reacts to jarring. It moves away from the objects with which it comes in contact in the water.

In order to see how the ameba responds to food, put small amounts of it in a culture. Watch how the ameba cells flock to the food. The food, perhaps by means of chemical attraction, acts as a stimulus to the cells. Unfavorable conditions such as dryness or cold cause some species of ameba to become inactive and to withdraw into a rounded mass. When favorable conditions return, the organisms resume activity.

Reproduction in the ameba. In the presence of abundant food and ideal conditions for growth, the ameba rapidly reaches maximum size. At this size the membrane surface is not large enough to supply the volume of cytoplasm with adequate food and oxygen or to remove waste. Reproduction now occurs by the process of fission. The nucleus divides by mitosis and its two portions move to opposite ends of the cell. The rest of the cytoplasm then separates gradually, forming two distinct masses. Each new mass has a nucleus and is capable of independent life and growth.

Biologists have found that, at a temperature of 86° F, an ameba cell requires approximately 20 minutes in order to make a complete division. When conditions for growth are ideal, each cell matures and divides again after about three days.

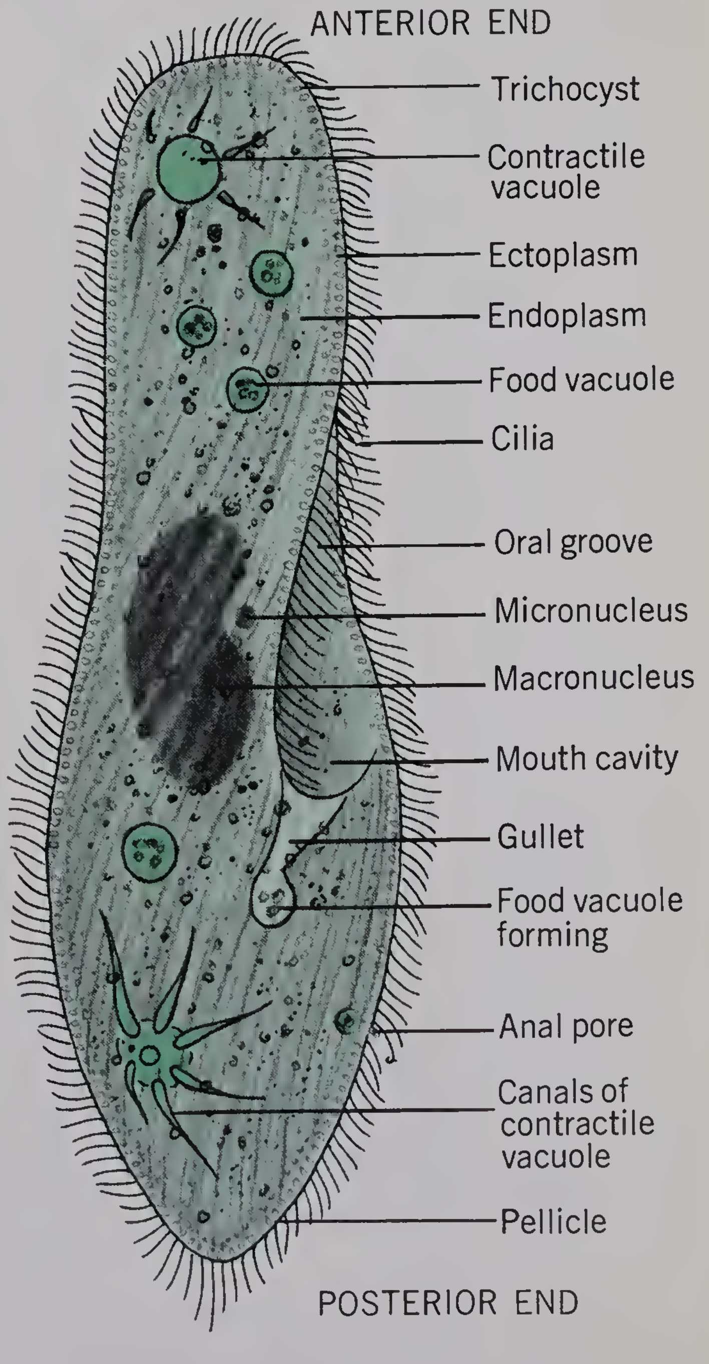
Paramecium, a complex protozoan. Various species of the genus *Paramecium* live in quiet or stagnant ponds where scums form. In order to culture them on the laboratory, submerged pond weeds may be collected, put in a jar with pond water, and set aside in a warm place for a few days. As the weeds decay, a scum forms on the surface, and large numbers of paramecia may be found.

When a drop of water containing paramecia is placed on a slide under the microscope, the most striking characteristic of this unicellular protist is its movement. It appears to swim rapidly through the thin film of water between the slide and cover glass. Actually, its rate of movement is quite slow — about three inches per minute; but the microscope magnifies the speed to the same extent as it does the object. A few strands of cotton or filaments of algae serve as effective barricades in preparing a slide for examination of these moving organisms. Methyl cellulose (which is now used as a wallpaper paste) may also be used to increase the viscosity of the solution. This slows down the animals, and allows an opportunity for the detailed study of structure.

The paramecium is shaped like a slipper (Fig. 18–3). Although it does not change its shape as an ameba does, it is by no means rigid. It often bends around an object it happens to meet when swimming. The definite shape of the cell is maintained by a thickened cell membrane called a ***pellicle*** surrounding the cytoplasm.

Paramecia move by hairlike cytoplasmic threads called ***cilia,*** which project through the cell membrane. These cilia are arranged in rows and lash back and forth like tiny oars. They cover the entire cell, but are most easily seen along the edges. Like flagella, cilia contain protein filaments, which biologists believe contract alternately to produce the beating. This form of movement places paramecium in the protist phylum ***Ciliophora.***

Another striking feature of the paramecium is a deep ***oral groove*** along one side of the cell. This depressed area is lined with long cilia that cause the animal to rotate around its long axis as it swims through the water. The paramecium has a definite front end, or ***anterior*** part, which is rounded, and a more pointed rear end, or ***posterior*** part — a perfect design in streamlining. The oral groove runs from the anterior end toward the posterior part. The action of the cilia lining the oral groove and the movement of the animal forward force food particles into the ***mouth cavity.*** The mouth cavity looks like the opening of a funnel, and it leads to a narrow tube, the ***gullet.*** Bacteria and other food particles forced into the gullet enter the cytoplasm within a ***food vacuole.*** When the food vacuole reaches a certain size, it breaks away from the gullet, and a new one begins to form.



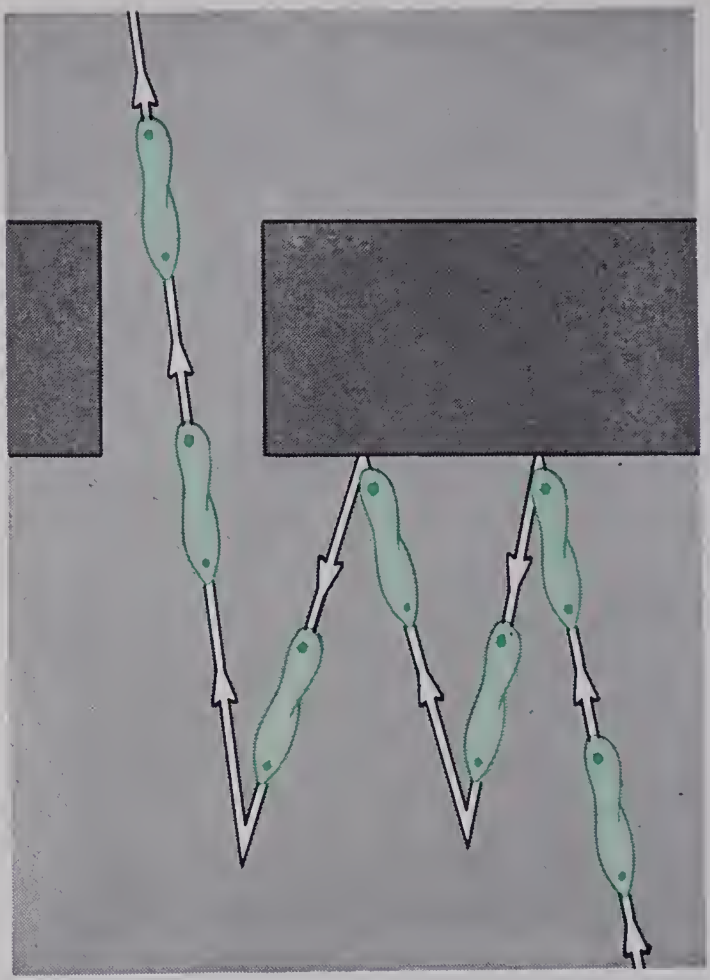
18-3 Compare this diagram of a paramecium with that of an ameba in Fig. 18-2. How are they alike and how do they differ?

The movement of the cytoplasm carries the vacuole in a circular course around the cell. During this circulation, digestion and absorption occur as in the ameba. Undigested food passes through a special opening in the pellicle called the ***anal pore.*** This tiny opening is located near the posterior part of the cell but is completely closed except when in use and is quite difficult to see.

The two ***contractile vacuoles*** have a definite location, one near either end of the cell. Surrounding each vacuole are numerous canals that radiate from the central cavity into the cytoplasm. The canals enlarge as they fill with water, after which their content is passed to the central cavity and emptied out at the surface through an opening.

As in the ameba the contractile vacuoles of the paramecium serve primarily to remove excess water that has entered with food and by osmosis. Some soluble waste may be eliminated by the contractile vacuoles, although most of the waste products appear to diffuse through the pellicle. Respiration in the paramecium is accomplished by diffusion of oxygen and carbon dioxide through the pellicle.

Sensitivity in the paramecium. The reactions of paramecium cells to conditions around them are remarkable, considering that this protist, like the ameba, has no specialized sense organs. Except when feeding, the cells swim constantly, bumping into objects, reversing, and moving around them in a trial-and-error fashion. This response to the stimulation caused by bumping into objects is called the *avoiding reaction* (Fig. 18–4). The reaction also occurs from such stimuli as excessive heat and cold, chemicals, and lack of oxygen. Paramecia tend to move into regions of low acidity, a response of value to the animal because bacteria form an important source of its food and bacteria accumulate on decaying organic matter, causing the water to be slightly acid.



18-4 This represents the avoiding reaction of paramecium. Note how the protozoan meets an obstacle, backs up, changes direction, and tries again.

The ***trichocysts,*** which normally appear as minute lines just inside the pellicle, are used as a means of defense. When a larger protozoan approaches, the trichocysts of the paramecium explode special protoplasmic threads into the water through tiny pores. These threads are quite long and give the organisms a bristly appearance. A bit of acetic acid or iodine added to some water that contains paramecia will often cause the trichocysts to discharge.

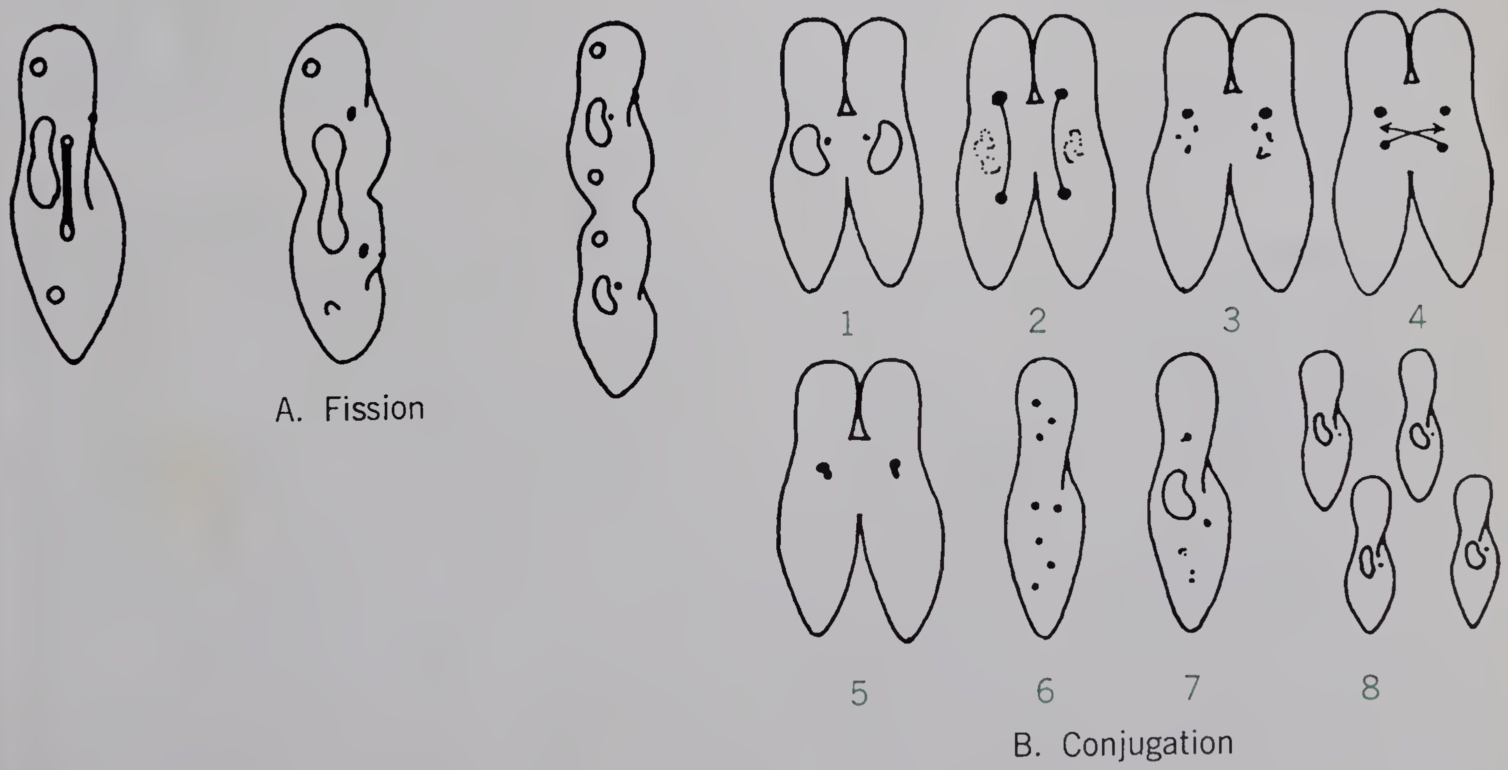
Reproduction in the paramecium. The paramecium has two different kinds of nuclei, both of which are located near the center of the cell. A large nucleus, or *macronucleus,* regulates the normal activity of the cell. Near the large nucleus is a small nucleus, or ***micronucleus,*** which functions during reproduction. Some species of paramecia have more than one micronucleus.

Reproduction may involve two distinct processes: fission and conjugation. Fission in paramecia involves the division of both the macronucleus and the micronucleus, after which two daughter cells form. Under ideal conditions fission may occur twice a day. This would produce over 700 generations per year. If all the daughter cells were to live and ideal conditions could be maintained, the total mass of paramecia would be many times greater than that of the earth in five years!

After several months of cell divisions, especially in the same environment, paramecia lose vitality and die unless they undergo ***conjugation.*** This process requires the mixing of two mating types, or sexes, which may be designated as + and −, or I and II. Exchange of nuclear materials during conjugation, resulting in revitalizing of the cells, may be summarized in the following steps:

1. Two cells unite at the oral grooves.
2. The micronucleus in each cell divides. The macronucleus degenerates.
3. The two micronuclei in each cell divide, forming four micronuclei, three of which degenerate.
4. The remaining micronucleus divides unequally, forming a larger and smaller micronucleus. The cells exchange smaller micronuclei.
5. The larger (stationary) and smaller (migrating) micronuclei fuse in each cell.
6. The cells separate. The fused micronucleus undergoes three consecutive divisions, forming eight nuclei.
7. Of the eight nuclei, four fuse and form a macronucleus, three degenerate, and one remains.
8. Two consecutive cell divisions occur, producing four small paramecia.

A flagellated protozoan. Several species of the genus *Euglena* live in freshwater ponds and streams. Under the



A. Fission

B. Conjugation

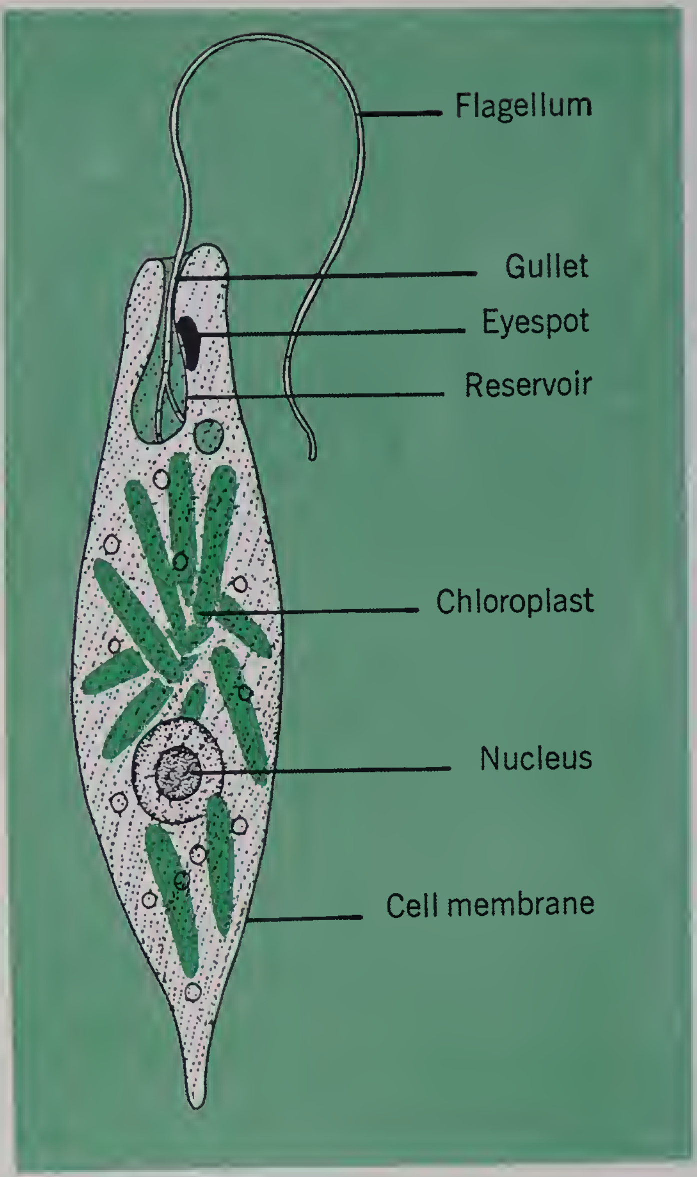
18-5 A. Reproduction in the paramecium. Trace the steps involved in fission. B. Conjugation of paramecia. Trace the exchange of nuclear materials.

microscope a euglena appears as a pear-shaped cell that swims about freely. The anterior end is rounded, while the posterior end is usually pointed (Fig. 18–6).

Since the euglenas possess some characteristics of plants and some of animals, they have been claimed by both botanists and zoologists. Because of one of their methods of locomotion, they are often placed in the protist phylum ***Mastigophora*** (mas-ti-*gahf*-o-ra), although some biologists put them in a phylum of their own. The organism swims by means of a flagellum attached to the anterior end and nearly as long as the one-celled body. The flagellum is held straight in front, and the tip is rotated, thus pulling the organism rapidly through the water.

Unlike other members of the phylum Mastigophora, the euglena has a second method of locomotion. This type of movement is so characteristic of the euglena that we call it ***euglenoid*** (yu-*glee*-noid) ***movement.*** It is accomplished by a gradual change in the shape of the entire cell. The posterior portion of the body is drawn forward, causing the cell to assume a rounded form, after which the anterior portion is extended, thus pushing the cell forward.

The internal features of the euglena show an interesting combination of plant and animal characteristics. The outer covering is a thin, flexible membrane like the membranes of typical animal cells. At the anterior end of the cell is a ***gullet*** opening which leads to an enlarged ***reservoir.*** Since the euglena has never been seen to feed, the gullet probably serves only as an attachment of the flagellum. Near the gullet is a very noticeable red ***eyespot.*** This tiny bit of specialized protoplasm is especially sensitive to light and serves to direct the organism to bright areas in its habitat. Near the center of the mass of cytoplasm is a large nucleus.



18-6 The structure of a euglena. Compare this protozoan with both a paramecium and an ameba.

Perhaps the most striking characteristic of the euglena is the presence of numerous oval chloroplasts scattered through the cytoplasm of the cell. Most species of euglena carry on photosynthesis and thus live quite independently of any outside source of food. However, some species lose their chlorophyll in periods of prolonged darkness and begin to absorb dissolved organic matter from the water in which they live. This organic matter passes through the cell membrane and into the cell where it is digested. Thus these organisms live an autotrophic life but can revert to a heterotrophic type of nutrition during unfavorable environmental conditions. Perhaps this is evidence that an organism like the euglena was the ancestor of all present-day protists.

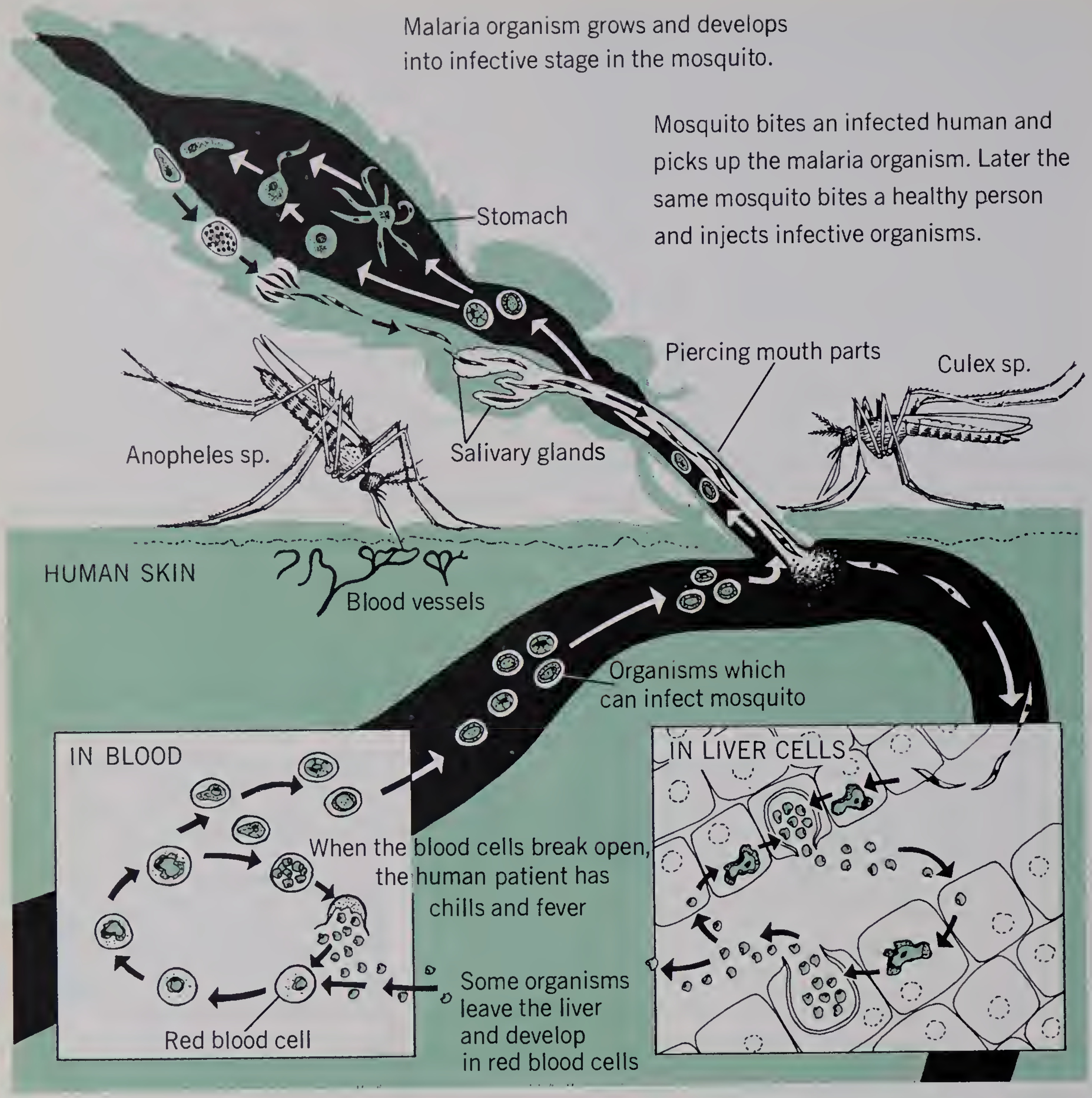
These organisms multiply rapidly by regular cell division under ideal conditions. A mature organism splits lengthwise, forming two new cells. One euglena may give rise to teeming millions within a few days if conditions for growth are favorable. Euglenas are often so numerous in ponds and streams that the water is a brilliant green.

The table below, comparing the ameba, euglena, and paramecium, may help you to review the degree of specialization of these three common protozoans.

The spore-forming protozoans. The spore-forming protozoans have no method of locomotion. They are placed in the protist phylum *Sporozoa.* In these protozoans reproduction by spores is accomplished in the following manner: first the nucleus divides into many small nuclei; then a small amount of cytoplasm surrounds each nucleus to form a spore; finally the protozoan breaks apart and releases these little spores.

COMPARISON OF THREE PROTOZOANS

	Ameba	*Paramecium*	*Euglena*
Form	Variable	Slipper-shaped	Pear-shaped
Locomotion	Pseudopodia (ameboid movement)	Cilia	Flagellum or euglenoid movement
Speed	Slow	Rapid	Rapid or slow
Food-getting	Pseudopodia surrounding food	Cilia in oral groove	Photosynthesis or absorption
Food taken in	Absorption	Through mouth cavity and gullet	Absorption
Digestion	In food vacuole	In food vacuole	In cytoplasm
Respiration	Diffusion of O_2 and CO_2 through membrane	Diffusion of O_2 and CO_2 through membrane	Diffusion of O_2 and CO_2 through membrane
Excretion	Through membrane	Through pellicle	Through membrane
Sensitivity	Responds to heat, light, contact	Responds to heat, light, contact, chemicals	Eyespot sensitive to light
Reproduction	Fission	Fission and conjugation	Fission


Malaria organism grows and develops into infective stage in the mosquito.
Mosquito bites an infected human and picks up the malaria organism. Later the same mosquito bites a healthy person and injects infective organisms.
Stomach
Piercing mouth parts
Culex sp.
Anopheles sp.
Salivary glands
HUMAN SKIN
Blood vessels
Organisms which can infect mosquito
IN BLOOD
IN LIVER CELLS
When the blood cells break open, the human patient has chills and fever
Some organisms leave the liver and develop in red blood cells
Red blood cell

18-7 The life cycle of *Plasmodium* is shown here. The *Culex* mosquito shown at the upper right does *not* carry *Plasmodium.*

The spores may be enclosed in a resistant wall or they may be surrounded only by a cell membrane.

Plasmodium (plaz-*moh*-dee-um), the parasitic protist that causes malarial fever in man and other warm-blooded animals, is a good example of a spore-forming protozoan. When a female *Anopheles* (a-*nahf*-e-leez) mosquito bites a person suffering from malaria, some of these protozoans pass into the insect's stomach. They grow, reproduce, and work their way into the mosquito's blood stream where they travel to the glands of the mouth. When this infected mosquito bites a human being, the *Plasmodium* is introduced into the human blood stream. From the blood stream it first invades the liver and then, about two weeks later, a red blood cell (Fig. 18–7). Here it forms so many spores that the membrane of the red blood cell breaks and liberates the young spores, as well as waste products from the parasite. Each spore finds a new red blood cell and the cycle is repeated.

In about two weeks after the infectious mosquito bite, there are about a billion parasites in the body. The chills, high fever, and sweating are caused by the release of wastes into the blood stream when the red blood cells burst.

There are three major species of *Plasmodium* that cause malaria in human beings. One species forms spores and bursts the red blood cells every day, so that the victim has chills and fever every 24 hours. Another species forms spores every other day, and a third species repeats its cycle every three days, thus causing attacks of chills and fever at intervals of 72 hours.

Other pathogenic protozoans. Many people are surprised to find that the great majority of human beings and most animals are infected with some type of protozoan. In man and most animals, the favorite place for these infections is the intestine, where a flourishing collection of these animals may be found. If you examine the intestinal contents of a freshly-killed animal under the microscope, you will probably see a great many protozoans. Some of them are harmless and may even be helpful, but many are pathogenic. The latter live on material in the intestine, robbing the host of its food. Some may invade the intestinal wall, show up later in the blood stream, and finally lodge in some other part of the body.

Water or food can be the source of infection by an ameba which causes *amebic dysentery*, a form of diarrhea, which results in poor nutrition and loss of water from the tissues of its human host. Although this disease more commonly occurs in the tropics, it is fairly common in the temperate zones. *African sleeping sickness* is caused by one of the parasites that move by flagella, the *Trypanosoma* (trip-*an*-o-sohm-a). It is carried to a human host by the *tsetse* fly. Many local and international health organizations are waging a determined battle to reduce the occurrence of these two diseases in the world.

Economic importance of the protozoans. The protozoans that live in fresh-water ponds and streams are of great economic importance, for they are the source of food for many small animals. Some salt-water protozoans secrete a hard wall made of calcium or silicon. These substances may form elaborately beautiful patterns. Members of this group, called the ***foraminifers*** and the ***radiolarians***, are responsible for the formation of many of the limestone and chalk deposits throughout the world. As they die their miniature skeletons fall to the bottom of the sea, and there, with billions of others, form a muddy deposit. If, as the earth's surface changes, this deposit dries out, it becomes hard.

Protozoans help to digest food in the intestines of some animals. In cattle they play such a role; and in the intestines of termites, protozoans are chiefly responsible for digesting the woody material the insects eat.

IN CONCLUSION

Protozoans are one-celled protists that function as complete organisms. The ameba, a shapeless mass of living protoplasm, lacks the specialization of other protozoan cells, yet, in its primitive way, performs all the processes of life.

Paramecia, on the other hand, illustrate a high degree of specialization. The euglena may perhaps be a connecting link between the plant and animal kingdoms, since it has certain characteristics of both groups.

Of great importance are the disease-producing forms of parasitic protozoans that live in the bodies of animals and man. Many of the protozoans that cause disease, such as the malaria parasite, require two hosts in order to complete the life cycle.

The next chapter will introduce us to some other very interesting protists that, although they do not contain chlorophyll, are more plant-like than animal-like.

BIOLOGICALLY SPEAKING

ameboid movement
anal pore
anterior end
avoiding reaction
cilia
Ciliophora
conjugation
contractile vacuole
ectoplasm
endoplasm
euglenoid movement
eyespot
food vacuole
foraminifers
gullet
macronucleus
Mastigophora
micronucleus
mouth cavity
oral groove
pellicle
posterior end
pseudopodia
radiolarians
reservoir
Sarcodina
Sporozoa
trichocysts

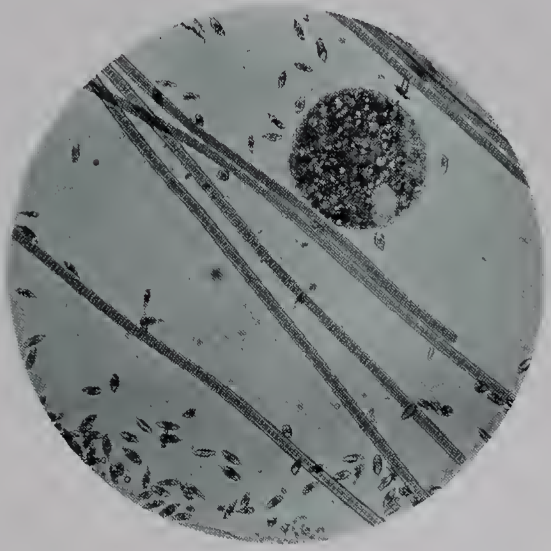
QUESTIONS FOR REVIEW

1. What are the four protozoan phyla? What characteristic divides them into phyla? Give an example of each.
2. Describe the way the ameba obtains its food.
3. Describe the way the paramecium obtains its food.
4. Explain how paramecium cells multiply. How are they rejuvenated?
5. In what ways does the paramecium show sensitivity?
6. List the plant-like and animal-like characteristics of the euglena.
7. Compare the locomotion of the ameba, the paramecium, and the euglena.
8. Why is the ameba considered simpler than the euglena and other protozoans?
9. Describe the life cycle of *Plasmodium*.
10. Name some of the pathogenic protozoans and the diseases they cause.
11. Name ways in which protozoans are important to man.

APPLYING PRINCIPLES AND CONCEPTS

1. Biologists frequently say that understanding the life processes of a single protozoan helps them to understand the life processes of complicated organisms like man. Why is this probably true?
2. What reasons can you give for the fact that the paramecium has two contractile vacuoles rather than one, like the ameba?
3. What stage in development would you consider best for treatment, once a person has become infected with the malarial parasite? Why?
4. What useful functions do certain protozoans perform in the human intestine?
5. In what way are protozoans important in a pond?

CHAPTER 19



THE FUNGI

What are fungi? When we speak of fungi, we refer in a broad sense to two phyla of protists that possess many plant characteristics. Because the fungi lack chlorophyll, they are either saprophytes or parasites and must live in association with organic nutrients. Fungi are common in all environments where suitable organic compounds are present. The great majority of them are terrestrial, but there are many aquatic forms. All produce spores that are carried either by air or by water.

In your study of the fungi, you will find considerable variation in the structure of the plant bodies as well as differences in reproductive structures. Biologists recognize only two phyla of fungi. The larger of the two, the ***Mycophyta*** (my-*kahf*-i-ta), consisting of the true fungi, is divided into four classes (see Appendix). The other phylum of fungi, the ***Myxomycophyta*** (mik-soh-my-*kahf*-i-ta), is made up of curious organisms called ***slime molds.*** At one stage in their life, some of these consist of flagellated cells, but have feeding stages in which large masses of protoplasm with many nuclei are not divided into separate cells. These molds are placed with the fungi only because their spores are borne in structures much like those of the true fungi.

Characteristics of the true fungi. More than 75,000 different species compose the four classes of true fungi. They vary in size from microscopic organisms to structures as large as mushrooms and puffballs.

Most of the true fungi have vegetative bodies composed of whitish or grayish filaments, each of which is known as a ***hypha.*** The hyphae vary in length and contain many nuclei. Some hyphae do not have their cells separated by cell walls, while others do have such walls. Therefore, you must think of a hypha as a long, continuous structure composed of many nuclei, but with or without cell walls.

The total mass of hyphae is a ***mycelium*** (my-*see*-lee-um). Although chlorophyll is not present in the hyphae of a mycelium, certain fungi contain yellow, orange, red, blue, or green pigments, which give them a special color.

All true fungi reproduce asexually by forming spores, which are carried to new environments by wind or water or contact with other agents. Most of them reproduce sexually as well.

Because of the enormous number of spores they produce, the fungi are widespread. These spores float through the air and lodge on objects. A suitable food supply or host will, almost invariably, be invaded by a fungus if conditions are suitable for growth. Fungi have no light requirements and actually thrive best in darkness. Moisture is, however, a growth requirement, as are warm temperatures, which usually favor

19-1 This photograph shows one of the slime molds in its fruiting stage, with spores ready to be released. (Walter Dawn)

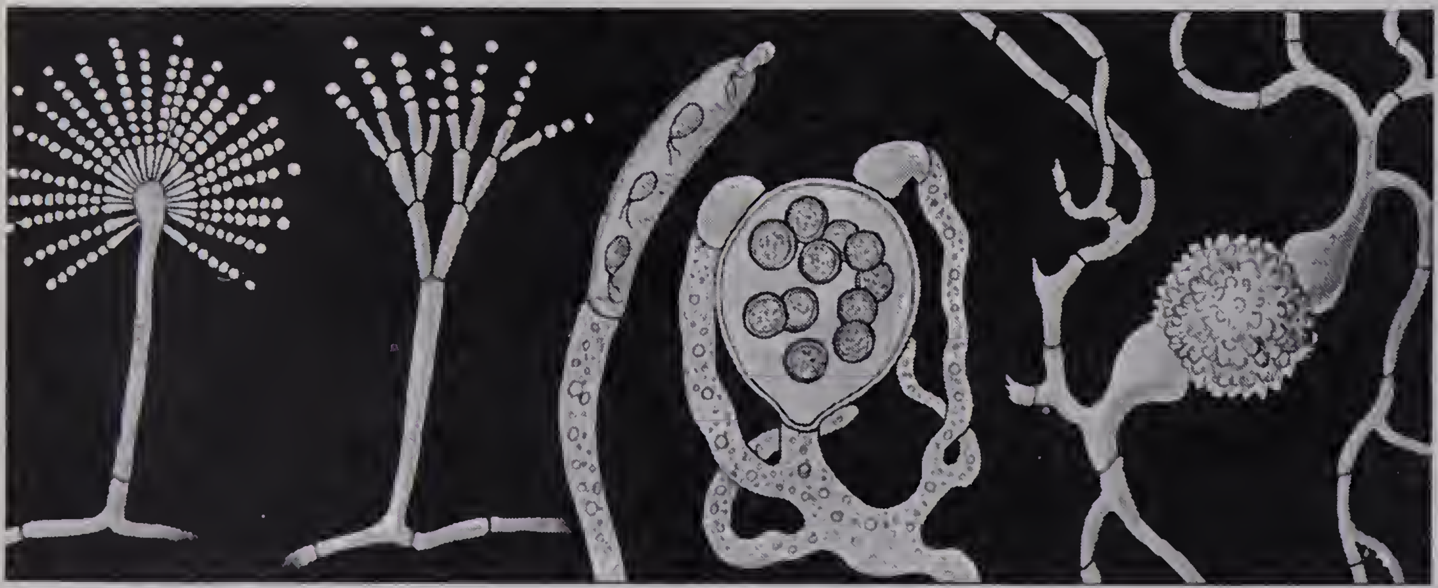
the growth of fungi. However, most fungi tolerate a wider temperature variation than do the majority of bacteria. Nearly all true fungi are aerobic, although a few live as anaerobes.

Molds — some of the most familiar fungi. We use the term ***mold*** to refer to many kinds of fungi. Some of these are Phycomycetes (fy-koh-my-*see*-tees), and resembles algae in structure; others are Ascomycetes (*as*-koh-my-*see*-tees) or sac fungi, so named because many of their group produce spores, usually eight in number, in saclike structures, each of which is called an ***ascus.***

Molds thrive in dark, moist places. While warmth stimulates the growth of many of them, others grow well at temperatures near freezing, which makes these organisms a serious problem in cold storage plants and in home refrigerators. Molds grow on nearly all foods as well as on wood, paper, leather, and many other organic substances. You may even find mold on the shoes you laid aside in your closet, if the summer months were warm and humid.

It would be incorrect to brand all molds as destructive. Certain of them are used in ripening cheeses. As you learned in Chapter 17, another mold, *Penicillium,* is directly responsible for the era of antibiotics.

Bread mold and its relatives. If you moisten a piece of bread, expose it to the air, and set it in a dark place for several days or a week, bread mold is almost certain to appear. *Rhizopus* (*ry*-zo-pus) is the genus name for this member of the ***Phycomycetes.*** The mold starts as a microscopic spore that grows



19-2 These are various types of molds, drawn as they appear under the microscope. What characteristics do all molds have in common?

Grade 8-9 68

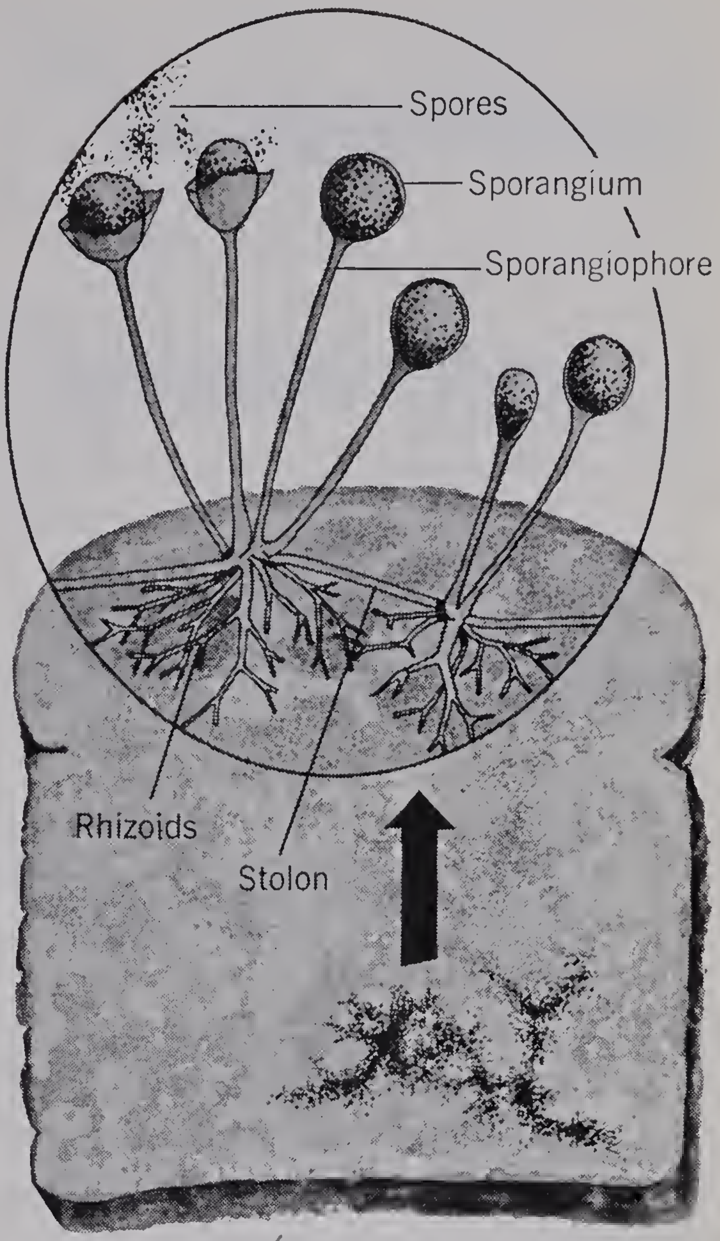
Grade 5

on the surface of the bread, forming a network of silvery, tubular hyphae. Within a few days, the mold covers the surface of the bread, forming a cottonlike mass of hyphae, the mycelium.

A portion of bread mold viewed with a hand lens or under the low power of the microscope reveals several distinct kinds of hyphae composing the mycelium. Those hyphae that spread over the surface of the food supply are called ***stolons*** (*stoh*-lonz). At intervals along the stolons, clusters of tiny rootlike hyphae, or ***rhizoids*** (*ry*-zoyds), penetrate the food supply and absorb nourishment. Rhizoids secrete digestive enzymes that act on the sugar, starch, and any other carbohydrates in the bread. These digested foods are then absorbed into the hyphae of the mold. The flavor, odor, and color spots that mold produces on bread and other foods are due to chemical changes resulting from the action of these enzymes. 145

After a few days of growth on the bread surface, black knobs appear among the hyphae of bread mold. Each black knob is a spore case, or ***sporangium*** (spor-*an*-jee-um), which is produced at the tip of a special ascending hypha, or ***sporangiophore.*** Each sporangium is a thin-walled case containing thousands of black spores. When the sporangium matures and dries out, its wall splits and releases the spores, which are blown around by air currents. Each spore may form a new hypha and, in a short time, an entire mature mold.

Sexual reproduction also occurs in bread mold by a form of conjugation. Although the individual hyphae in *Rhizopus* look alike, there are two physiologically different types, which may be designated as + and −. When a + hypha touches a − hypha at its tip, conjugation follows. Slightly back of the point of contact, walls are formed across the tips of the two hypha. This area at the tip, which has been cut off from the rest of the hypha, becomes a gamete. Thus one gamete is + while the other is −. Finally the contents of the two gametes fuse as the two hypha tips dissolve. The result of this fusion becomes a thick-walled zygospore, which rests until favorable conditions for germination occur. It may be carried a considerable distance by air currents or wind before it lands on a suitable host. When it does germinate, it produces a small hypha at its tip, and from this a sporangium develops. The sporangium

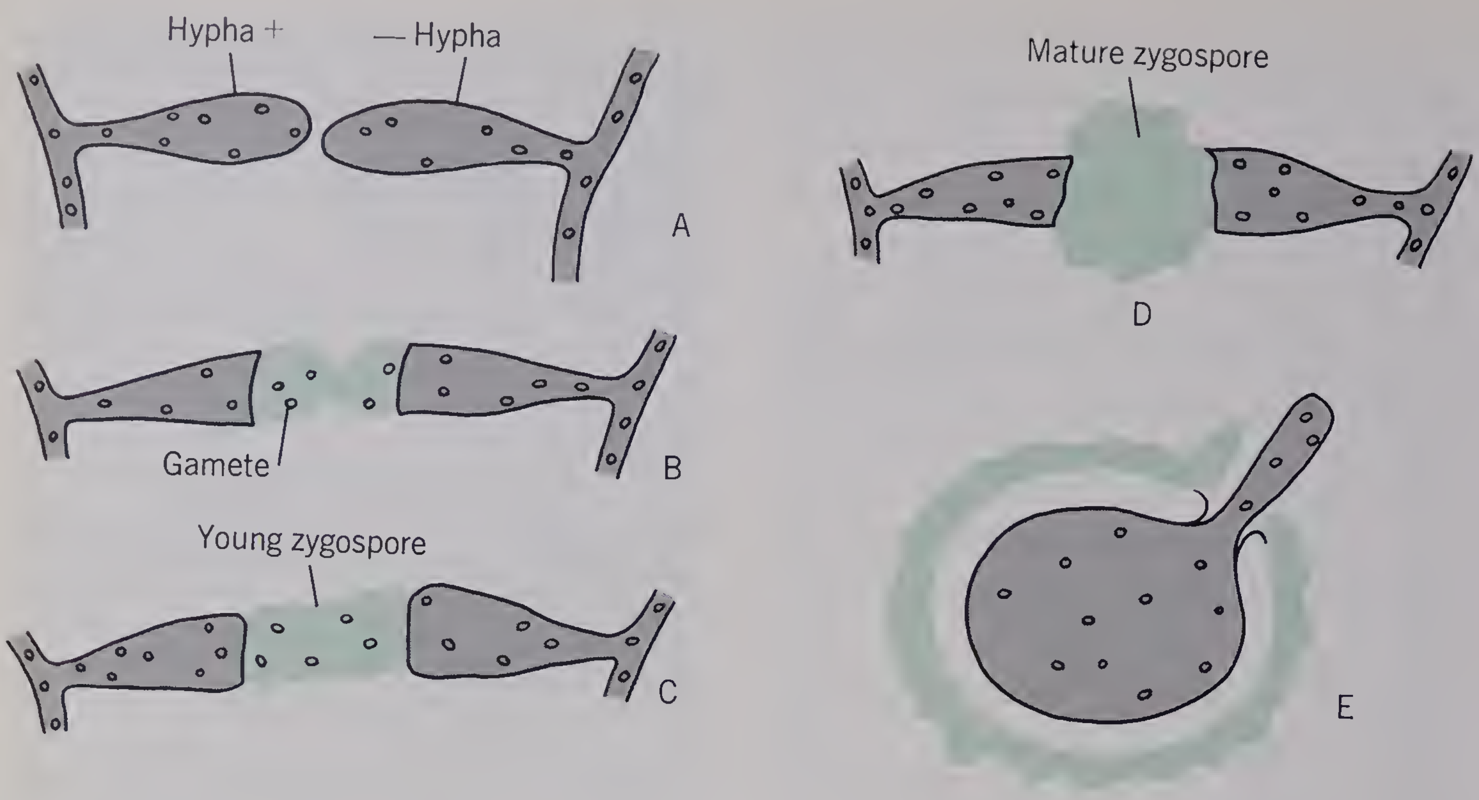


6

19-3 When you put a magnifying glass to a piece of bread which is covered with bread mold, you will see something like this. Note the rootlike rhizoids extending into the bread.

100/6

16.7



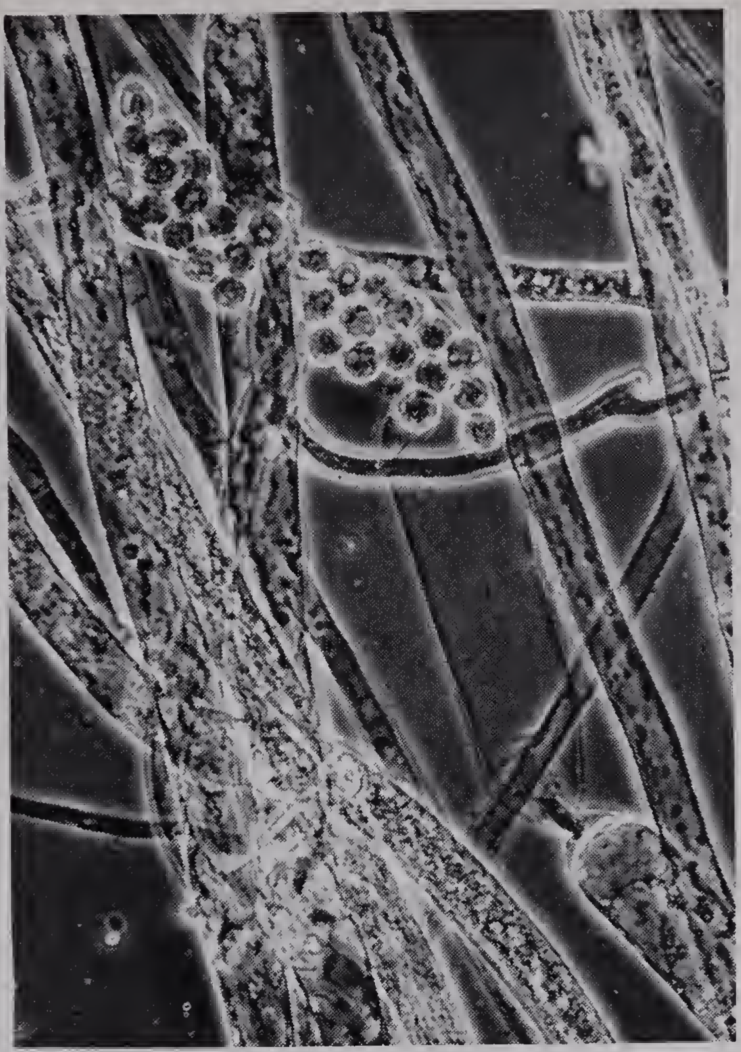
19-4 Sexual reproduction in bread mold. A through C represent various stages in formation of the zygote. D shows the zygospore and E represents the germination of the mature zygospore.

wall eventually ruptures and several spores are discharged, which then grow into a new mold. Note that the new spores are either + or − and that the hyphae they produce are also + or −.

The water molds, belonging to the genus *Saprolegnia* (sap-roh-*leg*-nee-uh), are relatives of the bread mold and belong also to the class Phycomycetes. They are similar to bread mold in having tubular hyphae. Certain of these molds are saprophytes and live on the bodies of dead insects and other animals in the water. Other water molds are highly destructive parasites. They invade the tissues of fish and other aquatic animals where they form patches of cottony tufts. These molds will, in time, kill the host animal. They are a constant problem to the aquarist and, in addition, destroy large numbers of native fish. The spores of water molds are equipped with two flagella which propel them to new locations.

Blue and green molds. The blue and green molds (*Penicillium* and *Aspergillus*) form the familiar powdery growth on oranges, lemons, and other citrus fruits. This powdery substance consists of spores in tremendous numbers, which form at the tips of hyphae. The mycelia of these molds are deeply embedded in the tissues of the food source. These molds may live on meat and other food products as well as on citrus fruits.

In this group of molds we find several of the most valuable of all fungus plants. Several species of *Penicillium*, one of the blue molds, are used in the processing of fine-flavored cheeses. Cheese manufacturers carefully grow these molds and add them to the cheeses at a certain point in processing. During the aging period, the mycelium of the mold grows through the cheese and, by enzyme activity, forms substances that add distinctive flavors. Among the more popular mold cheeses are Roquefort and Camembert. Both are cheeses in which *Penicillium* molds are used.



19-5 A water mold, *Saprolegnia,* produces zoosporangia, one of which is shown here releasing its zoospores into the water. (Walter Dawn)

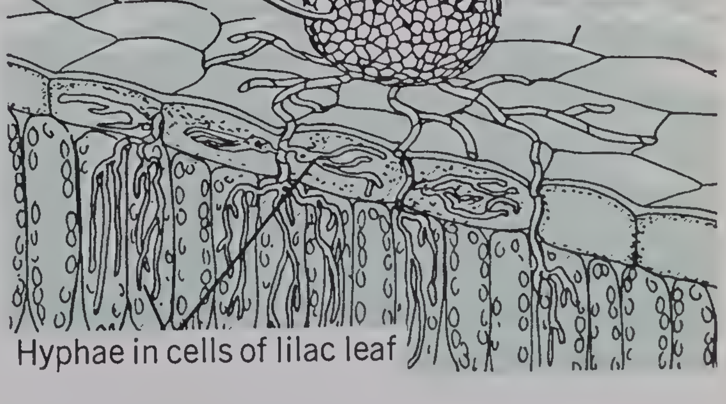
Today, however, *Penicillium* means much more to us than an organism for the flavoring of cheese. We associate it with one of the most notable medical advances of our time, the discovery of the antibiotic ***penicillin,*** which we discussed in Chapter 17.

Mildews – destructive plant parasites. The ***downy mildews*** belong to the Phycomycetes. Among the host plants of these dangerous parasites are radishes, mustards, white potatoes, sweet potatoes, cereal grains, sugar cane, tobacco, and lettuce. One of the downy mildews caused a famine in Ireland in 1845–1846 when it destroyed nearly the entire potato crop.

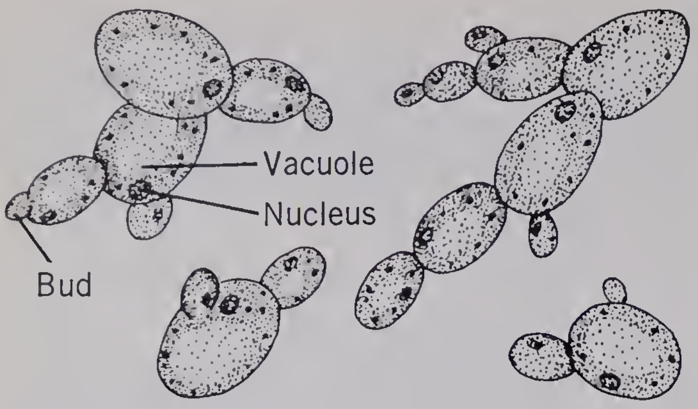
Many downy mildews form hyphae which grow down among the cells of the host plant. These hyphae absorb nourishment directly from the tissues of the host and thus are internal parasites. Other species form downy patches of surface hyphae, usually on leaves of the host, and send short, branching hyphae deep into the cells.

The ***powdery mildews*** belong to the class ***Ascomycetes*** and are not usually as destructive as downy mildews, since they are external parasites. They appear as whitish or dark-colored patches, usually on the leaves of the host plant. Among the host plants of these mildews are lilacs, grapes, roses, clover, apples, gooseberries, and many other flowering plants.

The familiar yeasts. The ***yeasts*** are one-celled fungi belonging to the Ascomycetes. The cells are usually oval. Each cell contains a nucleus and a vacuole. Note that these cells are not hyphae, since each yeast is a unicellular plant. Yeast cells reproduce by budding (see Chapter 8). When growth conditions are favorable, a bud starts as a small knob pushing out from the side of a cell. This bud, or daughter cell, grows rapidly and may produce another bud while still attached to the mother



19-6 The powdery mildew has as its host the common lilac bush. Why is it called an external parasite?



19-7 Yeasts are extremely beneficial fungi because of their ability to ferment sugars. Note the buds which are here shown in various stages of growth.

cell. Thus a fragile chain of cells, like a string of beads of varying sizes, results. When growth conditions become unfavorable, budding does not occur. Instead, a yeast cell may form spores, usually four in number, and thus becomes a spore-bearing sac, or ascus, characteristic of the Ascomycetes.

In connection with our discussion of Pasteur's work with fermenting beet juice, we mentioned that yeasts produce alcohol by fermentation. In this type of anaerobic respiration, carbon dioxide is given off as a fuel product. You can observe this activity by adding commercial yeast to a 10 percent solution of molasses (or some simple sugar) in water. Within a few hours the yeast cells multiply by budding in such numbers that they give the solution a cloudy appearance. Carbon dioxide rises through the solution as tiny bubbles, and you can smell the odor of the yeast.

Both products of yeast fermentation are valuable commercially. Yeast in dough forms bubbles of carbon dioxide which swell during baking and make the loaf light. The alcohol is driven off in the baking. Commercial alcohol manufacturers use yeasts to ferment various carbohydrate mashes.

Yeasts are important, also, as producers of vitamin B_2, or *riboflavin* (*ry*-boh-flay-vin). This vitamin is essential in normal growth and in the health of the skin, mouth, and eyes. Riboflavin remains in the yeast cells. To obtain it we must either eat the yeast cells or use a product made of ground yeast.

Wild yeasts are abundant in the air and ferment sugars in natural fruit juices. A few yeasts are pathogenic.

Other Ascomycetes. The ***cup fungus*** and ***morel*** are relatives of the yeast. These Ascomycetes are harmless saprophytes. Cup fungi grow on rotting wood and leaves and on organic matter in rich humus soils. Hyphae penetrate the food supply and absorb nourishment from the food material. The white, orange, or red cups are spore-bearing structures, composed of tightly massed hyphae. Many of these hyphae end in an elongated sac, or ascus, inside of which are eight spores.

19-8 The morel is a highly prized edible fungus. It is usually found in rich woods or in various shady places. (Hugh Spencer)

The morel, or sponge mushroom, is highly prized for its delicious flavor. This is one of the few mushrooms that can be safely eaten. It is easily recognized and is not related to the true mushrooms, many of which are inedible or poisonous.

Some of our most serious plant diseases are caused by parasitic Ascomycetes. Among these diseases are Dutch elm disease, chestnut blight, apple scab, peachleaf curl, and ergot disease of rye.

The basidiomycetes. Basidiomycetes are often called club fungi. Both of these names refer to a curious club-shaped structure formed at the end of certain hyphae. This ***basidium*** (ba-*sid*-ee-um), as it is called, usually bears four ***basidiospores*** externally. Four groups of fungi compose the class ***Basidiomycetes.*** These include the rust fungi, smut fungi, mushrooms and bracket fungi, and puffballs.

Rust fungi cause many serious plant diseases. There are more than 250 known forms of grain rust that attack wheat, oats, barley, and other cereals. They cause millions of dollars of damage to these crops annually.

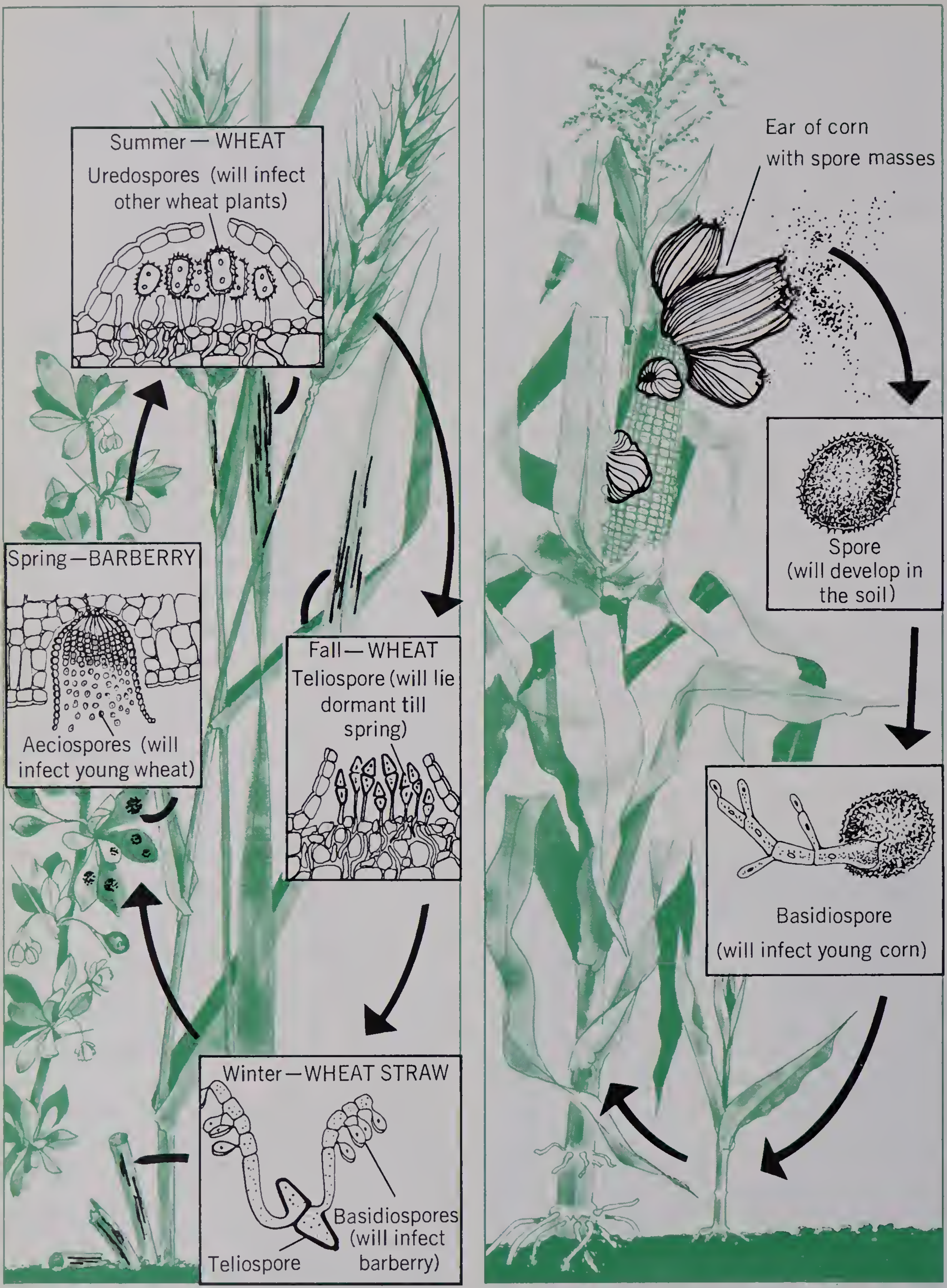
Wheat rust is one of the best known of these plant parasites, and is a special problem to farmers. It produces four kinds of spores in a very complicated life cycle that involves not just one but two host plants.

The rust makes its appearance on wheat during the late spring and early summer months, while the wheat is green and actively growing. The rust forms a mycelium which grows among the cells of the wheat stem and leaves. Tiny blisters appear along the surface of the stem and leaves where clumps of hyphae grow to the surface and discharge their spores. These spores are reddish-orange in color and are all one-celled. Biologists refer to them as red spores, or ***uredospores*** (yoo-*reed*-oh-spohrz). These uredospores can reinfect wheat and spread the disease rapidly by lodging on new plants. Later in the summer, when the wheat is ripening and the plants are turning yellow, a second spore stage appears. The same hyphae that produced red spores now produce black spores, or ***teliospores*** (*tee*-lee-o-spohrz). These are two-celled spores with heavy, thick, protective walls.

These black spores cannot reinfect wheat. Instead, they remain dormant through the winter on the wheat straw or stubble, or on the ground. Early in the spring, both cells of the teliospores germinate, producing four-celled basidia. One ***basidiospore*** forms on each of the four cells of the basidium. These spores are then carried away by the wind. If a spore lodges on a leaf of the common barberry (not the cultivated Japanese barberry), the life cycle continues. After complicated changes have occurred in the tissues of the barberry leaf, tiny cups appear on the leaf surfaces. These contain rows of ***aeciospores*** (*ee*-see-oh-spohrz), which drop from the cups and are carried by the wind to young wheat plants as much as 500 miles away. Infection of the wheat and production of red spores follows, thus completing the life cycle.

Both the wheat and barberry are necessary for completion of the cycle. Thus destruction of the common barberry bush is essential in controlling this disease, especially in the northern states where winters are more severe. However, in the southern states where there are mild winters, red spores may not be killed and can reinfect wheat directly.

Another rust, the *cedar-apple rust*, involves the red cedar tree and the apple and its close relatives. The *white-*


Summer — WHEAT
Uredospores (will infect other wheat plants)
Spring—BARBERRY
Aeciospores (will infect young wheat)
Fall—WHEAT
Teliospore (will lie dormant till spring)
Winter—WHEAT STRAW
Teliospore
Basidiospores (will infect barberry)
Ear of corn with spore masses
Spore (will develop in the soil)
Basidiospore (will infect young corn)

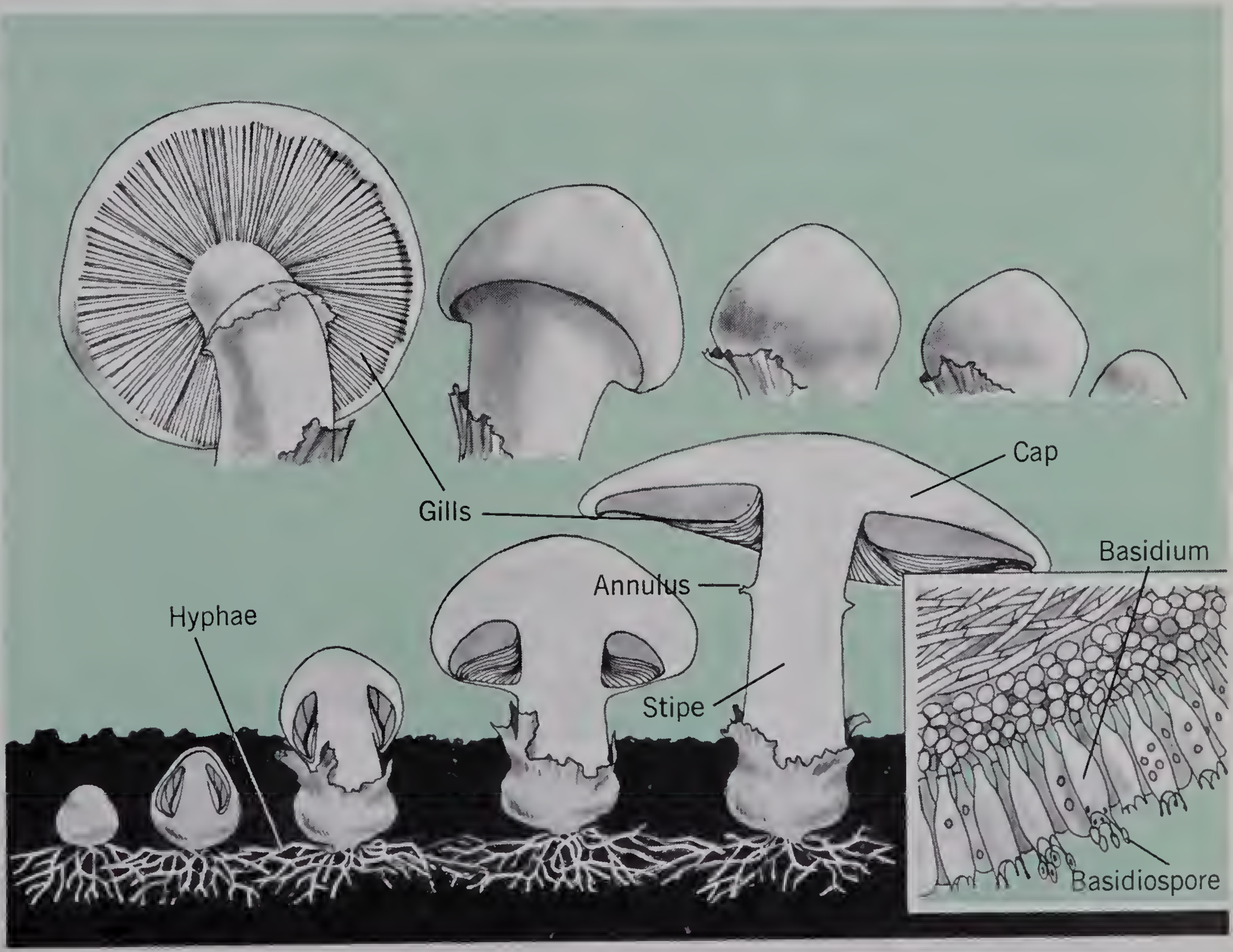
19-9 Left: the common barberry bush and the wheat plant are the two hosts necessary for the completion of the life cycle of the wheat rust. Right: trace the life cycle of the corn smut from the point at which masses of hyphae develop in the corn plant until the cycle is completed. How does this cycle compare with that of the wheat rust to the left?

pine blister rust causes serious damage to the white pine tree in one stage of its cycle and lives on the wild currant or gooseberry in another.

Smuts – parasites on cereal grains. The *smuts* attack corn, oats, wheat, rye, barley, and other cereal grasses, causing considerable damage.

Corn smut, one of the most familiar of this group, infects corn plants when they are young. Some weeks later, a grayish, slimy swelling appears on the ear, tassel, stem, or leaf. These swellings consist of hyphae. As the corn matures the hyphae produce large numbers of black, sooty spores, which are carried by the wind. These spores may infect nearby corn plants or lie dormant until spring. A germinating spore produces a four-celled, or sometimes three-celled, basidium. Each cell of the basidium produces a single basidiospore, as in the rusts. These basidiospores are carried by the wind to corn plants where they germinate and start a new smut infection. Corn smut may be controlled by burning infected plants, plowing under the stubble after the corn is cut, and destroying the unused stalks and leaves after the corn is picked.

Mushrooms – the best known of the fungi. We find *mushrooms* in orchards, fields, and woodlands, and popping up suddenly after a warm spring or autumn rain. We seldom see the vegetative mushroom plant. It is a mycelium composed of many silvery hyphae, which thread their way through the soil or the wood of a decaying log or stump.



19-10 This drawing illustrates the development of a mushroom as well as different views of the mature structure. The inset is an enlargement of a gill showing how the four basidiospores are attached to the basidium.

A mushroom mycelium may live many years, gradually penetrating more and more area of substrate. Digestive enzymes secreted by the hyphae break down organic substances in the host and change them to forms that can be absorbed and used as nourishment by the mushroom.

At certain seasons, especially in the spring and fall, small knobs develop on the mycelium just below the ground. These consist of masses of tightly-packed hyphae. These buttons develop into the familiar spore-bearing structure we recognize as a mushroom. The mature mushroom consists of a stalk, or ***stipe,*** which supports an umbrella-shaped ***cap.*** While pushing up through the soil, the cap is folded downward around the stipe. After forcing its way through the soil, the cap opens out, leaving a ring, or ***annulus,*** around the stipe at the point where the cap and stipe were joined.

Most mushrooms contain numerous platelike ***gills*** on the under surface of the cap, radiating out from the stipe like the spokes of a wheel. On the outside of each gill and extending all around it are hundreds of small basidia, each of which bears four basidiospores. It is estimated that a single mushroom may produce as many as 1,800,000,000 spores. These spores drop from the basidia when mature and are carried by the wind and air currents. Each spore forms a new mushroom mycelium if it happens to land in a new environment favorable for growth. If it does not — and not too many do — the spore dies. Some basidiospores are black while others are brown, yellow, white, or pink. If you turn the cap of a fresh ripe mushroom gills downward on a sheet of brown paper, you will usually get a large mass of spores and can identify their color easily.

Growth characteristics of the fungi. Many fungi grow in circles, which tells us about their food relations. In the fairy ring mushrooms, for example, the mycelium of the original plant digests the organic matter available at that spot. As the mycelium expands into the unused organic matter in the soil around it, new mushrooms are produced at the outer edge of this growing ring. You may see the same principle in mold growth in a culture dish. The newest part of the mold is on the outside of the circle, and the oldest portion is in the center.

Poisonous and edible mushrooms. The word "toadstool" is frequently used as a popular term for poisonous mushrooms. While many people claim to have methods of distinguishing edible from poisonous varieties, experts tell us there is no certain rule or sign that can be used to distinguish the two types of mushrooms. Frequently some of the most harmless-looking forms are poisonous and produce severe or even fatal effects if eaten. The only safe advice that can be given is to leave them alone unless you know exactly which forms are edible and which are poisonous.

Bracket fungi. The ***bracket fungi*** are the familiar shelflike growths seen on the stumps or trunks of trees. They may be either parasites on living trees, or saprophytes, living on dead wood. They are the most destructive of the wood-rotting fungi. The mycelium of the bracket fungus penetrates the woody tissue of the host and causes it to disintegrate internally. The shelflike reproductive body is telltale evidence of the damage that is occurring within the host. The bracket fungi are woody in texture when old and remain attached to the host year after year. New spore-producing hyphae form on the underside of the shelf, forming layers or rings of growth. Spores are discharged through tiny pores located on the underside of the shelflike growth.

Puffballs. The ***puffballs*** resemble mushrooms except that the reproductive structure never opens to discharge the spores. It merely dries and splits open, thus releasing the spores into the air. Puffballs are round or pear-shaped growths, usually white in color. Nearly all species are edible if collected when young and before the spores mature. No poisonous puffballs are known to exist.

Imperfect fungi. The biologist places all the fungi that do not belong in the other classes in the class ***Deuteromycetes,*** or *imperfect fungi.* They are considered imperfect because they reproduce only asexually. The majority of imperfect fungi are most like the Ascomycetes.

Many of the imperfect fungi are of great importance as parasites in man, animals, and plants. Among the plant diseases associated with this group are those of corn, oats, wheat, citrus fruits, tomatoes, cabbage, lettuce, beans, and apples.

The ringworm fungi produce several skin infections in man, including ringworm, barber's itch (ringworm of the scalp), and the all too familiar athlete's foot. Thrush is a serious infection of the mucous membranes of the mouth and throat caused by an imperfect fungus resembling the yeasts.

Fungi and higher plants living together. Biologists have been investigating an interesting relationship between certain fungi and the roots of higher plants. Many Ascomycetes and Basidiomycetes that live in the soil are parasites on the roots of trees and shrubs. Some form a mass of hyphae around a young root. Others enter the root and live as internal parasites. It is believed that the fungi aid the root in absorbing minerals, especially nitrogen compounds. The fungi, of course, take nourishment from the root tissues.

IN CONCLUSION

The fungi comprise two phyla whose members lack chlorophyll. Fungi must therefore grow on organic materials because they cannot make their own food. If the food source is living material, the fungus is a parasite. If the source is nonliving, the fungus is a saprophyte.

Among the most important groups of fungi are mushrooms, bracket fungi, molds, mildews, rusts, smuts, blights, and yeasts.

Fungi may be beneficial or harmful, depending on their source of food. Among the valuable fungi are certain of the mushrooms, some of the molds, and yeasts. Certain molds, mildews, rusts, and smuts are blight-causing organisms and among the most destructive in the entire plant kingdom.

In the next chapter we shall examine six phyla of aquatic or marine protists (although a few are terrestrial) known as the algae. Here we find seaweeds and kelps as well as many organisms that thrive in freshwater ponds, lakes, and streams.

BIOLOGICALLY SPEAKING

aeciospore
annulus
Ascomycetes
ascus
Basidiomycetes
basidiospore
basidium
cap
Deuteromycetes
gill
hypha
mycelium
Mycophyta
Myxomycophyta
penicillin
Phycomycetes
rhizoid
sporangiophore
sporangium
stipe
stolon
teliospore
uredospore

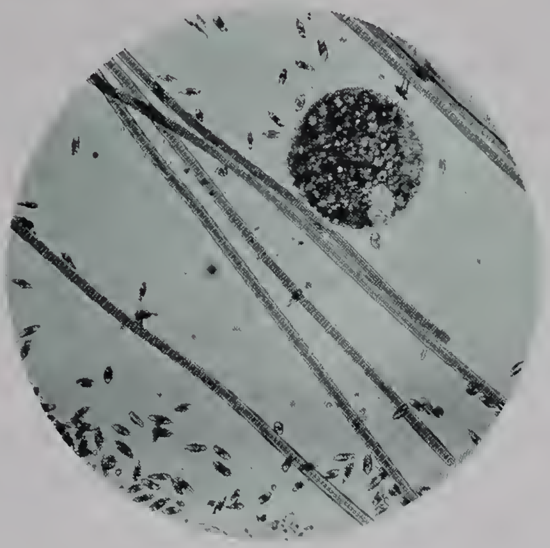
QUESTIONS FOR REVIEW

1. What one reproductive characteristic do all fungi have in common?
2. Name the classes of fungi. Which of these classes are included in the true fungi?
3. Describe the mycelium of a true fungus.
4. What different kinds of hyphae make up a bread mold plant?
5. How can bread become inoculated with bread mold even though there may be no molds close by?
6. Discuss several ways in which *Penicillium* molds are valuable.
7. Why are downy mildews more destructive to higher plants than the powdery mildews?
8. Discuss budding in yeast.
9. How are the products of yeast fermentation used commercially?
10. Describe the production of four kinds of spores by wheat rust.
11. What stage in the life cycle of corn smut relates it to the rusts?
12. Describe the structure of a mushroom reproductive body.
13. How are puffballs different structurally from mushrooms?
14. Name several human infections caused by imperfect fungi?

APPLYING PRINCIPLES AND CONCEPTS

1. Mildew diseases of higher plants are more prevalent some summers than others. Account for this.
2. Sweet cider will ferment rapidly in a warm place even when it is in a tightly closed container. Explain why.
3. Why are yeast preparations valuable in treating acne and other skin disorders?
4. Why is a severe epidemic of wheat rust likely to follow a mild winter?
5. Explain why certain kinds of mushrooms and molds often grow in a circular ring.

CHAPTER 20



THE ALGAE

The occurrence and classification of algae. Floating or submerged masses of blue-green, green, or yellowish algae are familiar to anyone who has walked along the shore of a pond or stream or rowed across a lake in spring, summer, or fall. These are algae, which are the most abundant form of vegetation in aquatic environments. Some forms cling to rocks along waterfalls or rapids; others occur on seacoasts where they are exposed during low tide. Still others grow on the bark of trees, on fence posts, or on wet stones.

Some algae are unicellular while others are multicellular. Some one-celled forms may be as small as 1/25,000 of an inch, while a giant kelp may be over 100 feet long. Approximately 30,000 species of algae are known to the biologist and more will probably be found as new areas of the world are explored for science. The classification of the algae is difficult, and various systems for grouping them have been proposed. One commonly accepted today places them into six phyla in the protist kingdom (see Appendix).

It is very likely that algae and fungi evolved from a common ancestor. We know that algae are ancient, for fossils have been found in Archeozoic and Proterozoic rock. They were dominant during the Silurian period of the Paleozoic era.

The cells of all algae contain chlorophyll and carry on photosynthesis, just as higher plants do. In fact, algae are the principal food producers in water environments. Furthermore, the oxygen released from algal cells during photosynthesis dissolves in water and becomes available for the respiration needs of the many aquatic animals living among the algae. Thus this oxygen is as important as the sugar, starch, oils, and other organic products of the chemical activity of algal cells.

Structure and reproduction of algae. Many algae are one-celled organisms. Some float in the water or settle to the bottom, while others swim about like animals. Many algae form colonies consisting of two or more individual cells attached to each other. Even though they are attached to one another, all the cells in a colony of algae live independent lives. They do not depend on one another as do the cells of higher plants.

Many algae form threadlike colonies in which the cells are attached end to end. We refer to these linear groups of cells as ***filaments.*** Other algae form flat plates of cells or globular or spherical colonies. The cells of many species secrete gelatinous cell coverings that protect the cells from water loss and unfavorable environmental conditions. These gelatinous secretions make many algae slimy in texture and difficult to grasp in the water.

Many forms of reproduction are carried on among the algae. All of them carry on fission. When a one-celled alga divides, two new organisms result. Cell division in a colonial form merely increases the size of the colony.

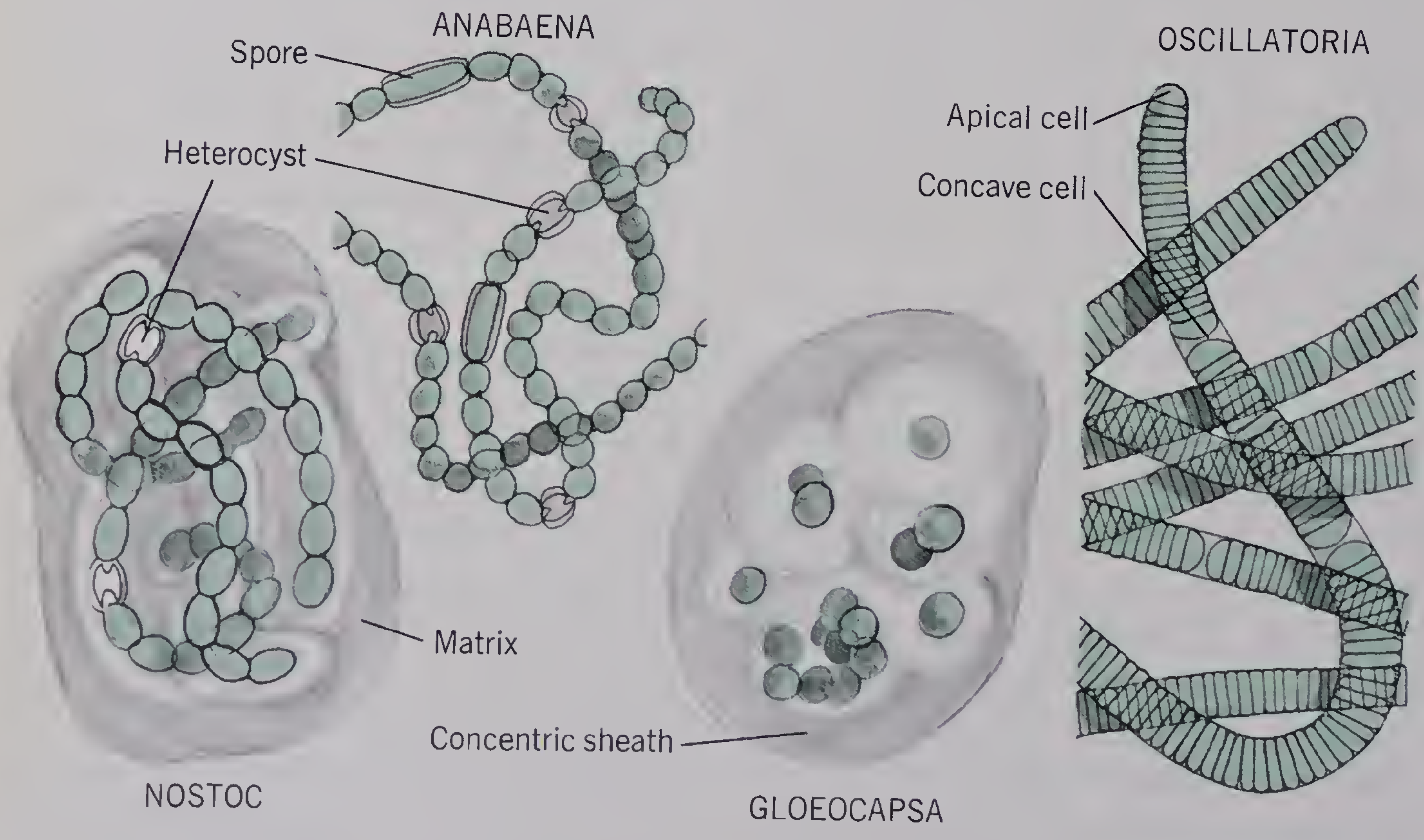
Colonies of algal cells are frequently broken apart by currents of water, passing fish, or animals feeding on them. We refer to this mechanical separation of cells in a colony as ***fragmentation.*** This breaking up of colonies merely multiplies the number of colonies, since the separated cells continue normal growth and multiplication.

Many algae reproduce asexually by forming spores. These spores contain a portion of the protoplasm of the mother cell that formed them, and each one may swim or float to a new location. There the spore may grow immediately into a new alga or may lie dormant for weeks or months. When environmental conditions are suitable, it will then form a new algal cell. By means of spores, many algae spread over wide areas in a single growing season.

Reproduction also occurs sexually by both isogametes and heterogametes. Often the zygote undergoes a resting period after which it produces spores. These spores then give rise to a new plant.

Because the cells of algae are so small, and because the behavior of the cells during reproduction is so specific, a microscope is almost a necessity in studying algae. If you plan to observe living forms of algae, your microscope will reveal fascinating activities in just one drop of pond water.

Blue-green algae. The ***blue-green algae*** are all one-celled protists which usually form colonies. Some occur in filaments, while others consist of slimy masses of material in which the algal cells are embedded. You can find various blue-green algae in almost every roadside ditch, in ponds, and in streams. To-



20-1 This diagram shows the structure of four rather common blue-green algae. What similarities and differences do you note?

gether with the viruses and bacteria, they are considered among the most primitive of plants.

Blue-green algae thrive during the hot summer months, and are a constant problem in drinking water and swimming pools. They give water the odor characteristic of stagnant pools and certain streams. For this reason biologists check the sources of public water supply regularly for the amount of blue-green algae it contains.

The phylum name ***Cyanophyta*** (sy-a-*nahf*-i-ta) refers to a blue pigment, ***phycocyanin*** (fy-koh-*sy*-a-nin). This, together with chlorophyll, gives these algae their characteristic blue-green color. Colors of various species range from bright blue-green to almost black. However, a few species contain a red pigment. One of these forms appears periodically in the Red Sea, which gave it its name in early times.

The cells of blue-green algae are primitive and simple in structure. They lack a nuclear membrane and the nuclear material may appear to be scattered throughout the protoplast. The chlorophyll and other pigments are located on membranes rather than in chloroplasts. None of these blue-green algae reproduce sexually as do the higher fungi. Instead, their usual method of reproduction is by simple fission.

Representative blue-green algae. We have selected four common blue-green algae as representatives of this important group. One of the most curious is *Nostoc* (*nos*-tok). You will find it in mud and sand usually just at the point where the ripples from a pond or lake strike the shoreline. A *Nostoc* colony looks like a small, gelatinous ball, ranging in size from a pinhead to a marble, often likened to a peeled grape (Fig. 20–1). The ball is composed of a gelatinous ***matrix.*** Embedded in the matrix are many curved and twisted filaments made up of tiny spherical cells, each of which resembles a pearl bead in a necklace. Distributed along the filaments are curious empty cells with thick walls and pores at either side where they join other cells. These are ***heterocysts.*** Biologists believe that they may be the remains of spores that have lost their content and ceased to function. They enable the filaments of *Nostoc* to break into shorter pieces. *Nostoc* is, fundamentally, a one-celled plant that forms filamentous colonies surrounded by a gelatinous matrix. Each time a cell divides by fission, it forms two small cells of equal size and thus increases the length of the filament. This is the only method of reproduction in this primitive alga.

Anabaena (an-a-*bee*-na) is a relative of *Nostoc*, as seen by the similarity in cells and filaments (Fig. 20–1). Filaments of *Anabaena*, however, are solitary and do not occur together as the filaments of *Nostoc* do. Another difference is the production of spores in *Anabaena*, which can be recognized easily as enlarged, oval cells in the filaments. Each spore is protected by a thickened wall and contains an abundance of stored food. Each spore eventually separates from the parent filament and germinates in a new location.

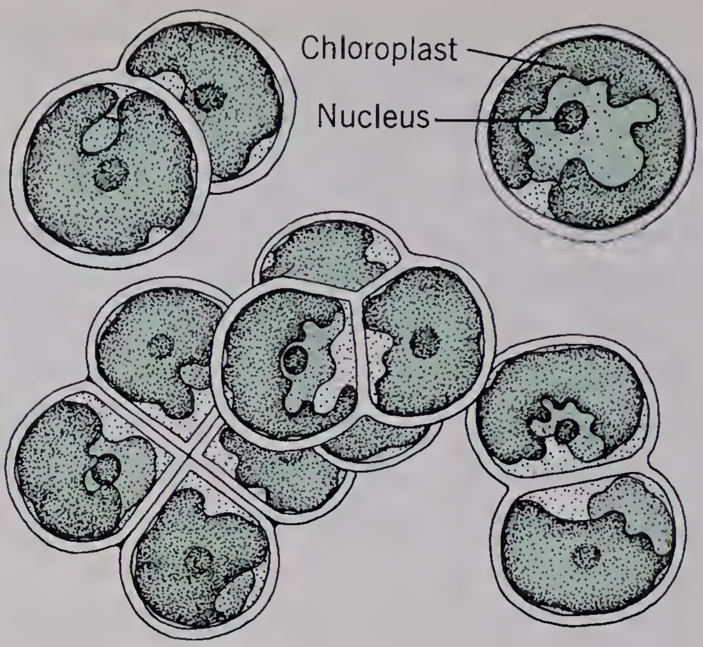
Gloeocapsa (glee-oh-*kap*-sa) is one of the most primitive blue-green algae (Fig. 20–1). It can be found on wet rocks and often grows on moist flowerpots in greenhouses, where it forms a slimy, bluish-green mass. The individual cells of this one-celled alga are spherical or oval. The diffused blue and green pigments lie in a zone near the wall. Dark granules may be seen deeper in the cell. Each cell of *Gloe-*

ocapsa secretes a slimy sheath. When a cell divides, each new cell secretes its own sheath within the old one, thus forming characteristic layers of sheaths. A colony of *Gloeocapsa* often contains hundreds of cells, joined by their sheaths in a gelatinous layer.

Oscillatoria (os-il-a-*tor*-ee-a) is a filamentous blue-green alga composed of many narrow, disk-shaped cells resembling a stack of coins. The tip, or ***apical*** (*ap*-i-kal) ***cell,*** is round on one side in many species. Filaments of *Oscillatoria* sway gently back and forth in the water, a characteristic that gave the alga its name. When one cell in the filament dies, the ones on either side bulge into its place and produce a curious ***concave cell*** (Fig. 20–1). Concave cells are weak places in the filament and cause the plant to break into shorter pieces. *Oscillatoria* becomes abundant in ponds and streams during warm weather.

Green algae. The ***green algae*** belong to the phylum ***Chlorophyta*** and vary from one-celled forms to colonial forms composed of a large number of cells. They are for the most part fresh-water algae, although certain members of the group live in strange and interesting environments. Many kinds live in the ocean and a few live in bodies of water even higher in salt concentration than the ocean. Some, to the amazement of scientists, thrive in hot springs. One species grows on the hair of the South American three-toed sloth and gives this animal its peculiar green appearance. Other strange environments include the bodies of protozoans, sponges, and jellyfish.

The cells of green algae have a definitely organized nucleus. Carotinoid pigments, including chlorophyll and also the xanthophylls and carotenes, are contained in the plastids. These pigments combine to give the algae colors ranging from grass green to yellowish-green. Green algae form sugar during photosynthesis and convert it to starch for storage in the cells. Reproduction is both by fission and by asexual spores, and some of the genera reproduce by forming sexual gametes.



20-2 The round cells of the green alga *Protococcus* may occur singly or in colonies of two or more.

Protococcus, a common green alga. *Protococcus* is one of the most common of green algae, and is an exception among algae in that it does not live in water. Most of you may not have recognized it as an alga because it grows on the trunks of trees. You may also find it on unpainted wooden buildings and fences. During dry weather you seldom see it, but in wet weather it is very evident. It is most common on the north side of tree trunks because bark is more moist on the shaded side.

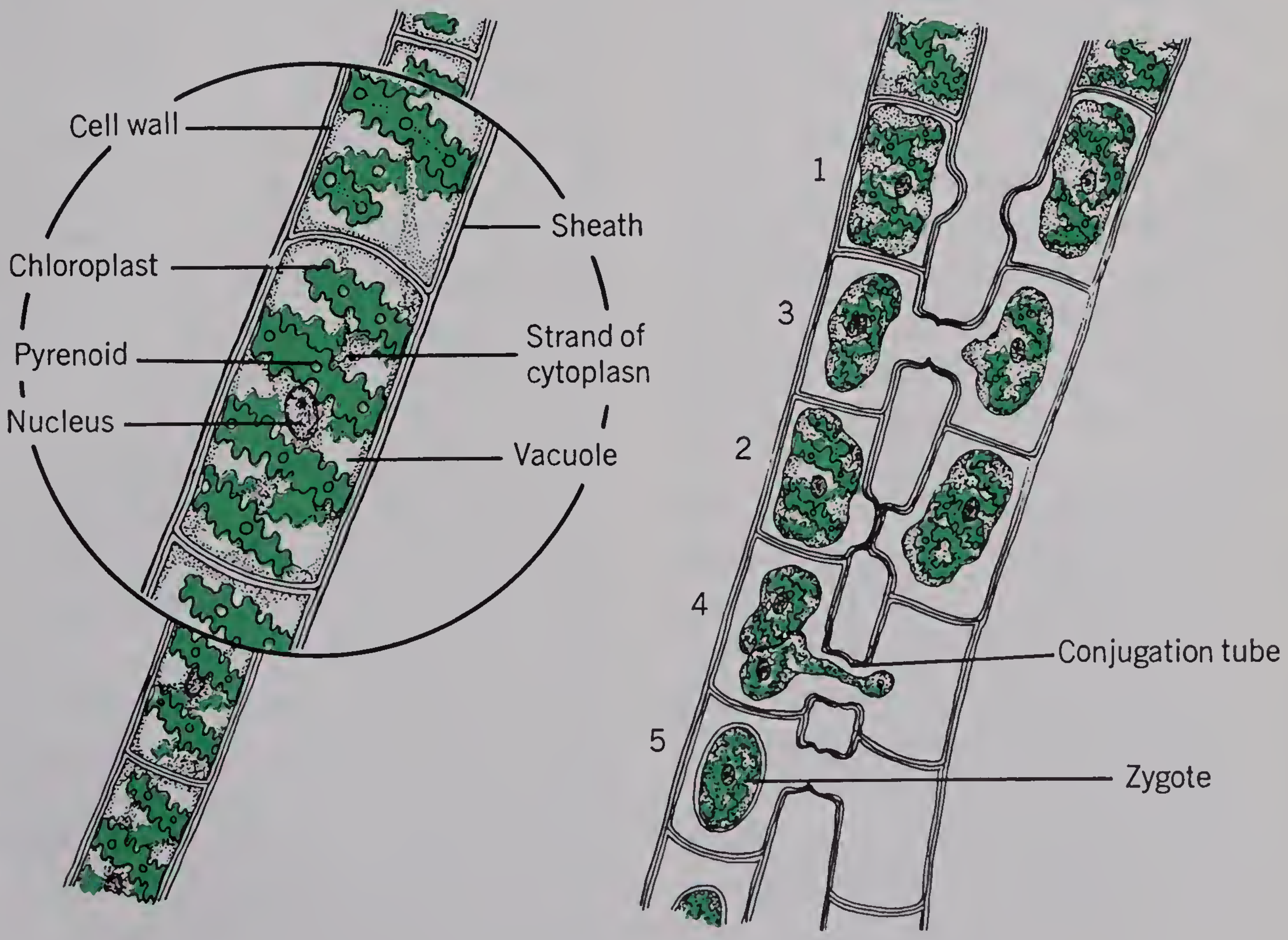
The cells of *Protococcus* are spherical or somewhat oval (Fig. 20–2). Each contains an organized nucleus and a single large chloroplast. The cells are so small that many thousands cover only a few square inches of bark. They may be carried from tree to tree by birds and insects as well as by the wind during dry weather. Since *Protococcus* is a green protist, it requires no nourishment from the tree on which it grows.

Reproduction in *Protococcus* is by fission only. Following divisions the cells tend to cling together. This produces the cell groups shown in Fig. 20–2.

Chlorella is a single-celled spherical alga somewhat resembling *Protococcus*. It has a large, cup-shaped chloroplast. This alga is especially interesting to the biologist because several of its species live in the cells or tissues of protozoans, sponges, and jellyfish. As you learned in Chapter 6, it has also been the subject for much research in the study of photosynthesis as well as in studying alga cultures as a possible source of food and oxygen.

Spirogyra, a filamentous green alga. Almost any pond or quiet pool will have bright green masses of threadlike *Spirogyra* (spy-roh-*jy*-ra) during the spring and fall months. The unbranched filaments of this green alga range from a few inches to a foot or more in length. Under a microscope, a thread of *Spirogyra* looks like a series of transparent cells, arranged end to end like tank cars in a train (Fig. 20–3).

Each cell has one or more spiral chloroplasts which wind from one end of the cell to the other. On the ribbonlike chloroplasts are small protein bodies surrounded by a layer of starch. These ***pyrenoids*** (*py*-re-noidz) are food reserves of the cell. The nucleus is embedded in cytoplasm and is suspended near the center of the cell by radiating strands of cytoplasm anchored to the pyrenoids.



20-3 Left: one cell of the green alga *Spirogyra*, showing the ribbonlike chloroplast. Right: conjugation in *Spirogyra*. Each step in the process is numbered in sequence for your further study.

Most of the cytoplasm lies in a layer close to the wall, leaving a large central vacuole which fills with water and dissolved substances. A thin, gelatinous sheath surrounds each cell and gives the filaments of *Spirogyra* a characteristic slippery feeling.

On a bright day photosynthesis takes place rapidly. Bubbles of oxygen stream from the cells and collect among the filaments, which cause a mass of *Spirogyra* to float to the surface. During the night the oxygen dissolves in the water and allows the mass to sink. You can see floating colonies of *Spirogyra* and other algae on the surface of a pond, especially in the afternoon of a bright day.

Spirogyra reproduces in two ways. All the cells of a filament undergo fission at certain time intervals. Since the divisions are always crosswise, fission adds to the length of the filaments.

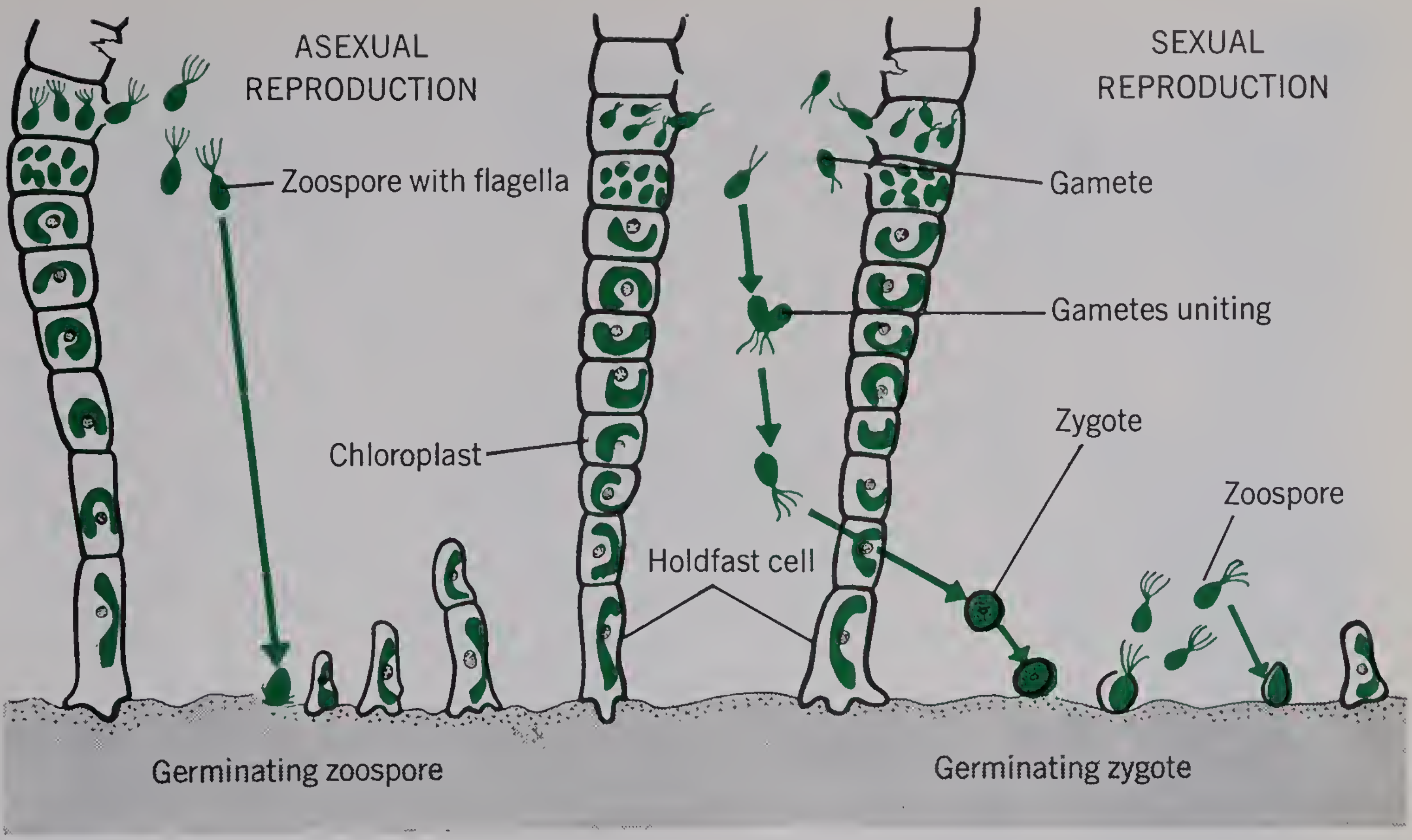
The second method of reproduction is by conjugation, which, as you learned in Chapter 18, is sexual. It occurs when weather conditions are unfavorable for normal growth by fission. You are likely to see it in material collected early in the summer, at the close of the spring growing season, and again in the fall with the approach of cold weather.

Conjugation involves two filaments of *Spirogyra*, which line up parallel to each other. A small knob grows out from each cell on its inner side, as shown in Fig. 20–3. Then each knob grows until it touches the knob of the cell across from it. Soon the tips of the knobs dissolve and form a passageway between the two cells, which results in a ladderlike arrangement. The content of one cell then flows through the passageway and unites with the content of the other cell. The fused content of the two cells forms a spherical or oval zygote, which is soon surrounded by a thick protective wall. It is interesting to note that the content of a cell in one filament moves across to the cell of the other, thus producing one filament of empty cells and another containing rows of zygotes. This alga reproduces much as does *Rhizopus*, the bread mold, except that the filaments are not definitely + or −. They do differ physiologically, however.

Soon after conjugation is completed, the zygotes fall from the cells holding them and undergo a rest period. The thick wall protects the zygote from heat, cold, and dryness. As a zygote, *Spirogyra* can survive a long, cold winter, a summer drought, or may even be transported from one pond to another by a bird or other animal. When conditions are favorable for growth again, the content of a zygote resumes activity. The nucleus divides by meiosis, resulting in four nuclei, each containing the haploid number of chromosomes. Three of these nuclei die. The remaining one becomes the nucleus of the new *Spirogyra* cell that grows from the zygote and establishes a new filament by successive cell divisions.

The life history of Ulothrix. *Ulothrix* (*yoo*-loh-thriks) is interesting to the biologist because it represents a group of green algae with somewhat different reproductive processes. You can find this alga attached to rocks in swift-flowing, shallow water. The short filaments are anchored by a special cell with fingerlike projections, known as a ***holdfast.*** The cells above the holdfast each have a chloroplast shaped like an open ring (Fig. 20–4).

Under ideal growth conditions, a cell of *Ulothrix* undergoes a series of



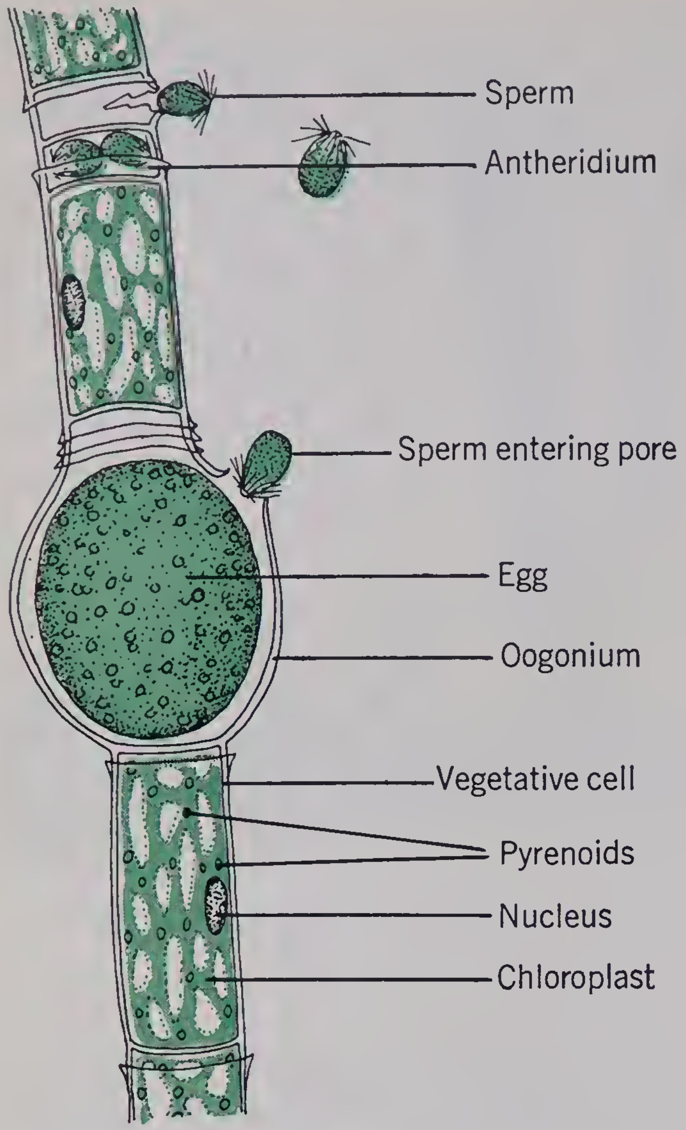
20-4 The drawing on the left represents asexual reproduction in *Ulothrix,* while that on the right illustrates sexual reproduction.

mitotic divisions followed by a splitting up of the cell content into 2, 4, 8, 16, or 32 oval bodies. Each of these bodies is a new cell because it contains a nucleus and chloroplast. Each one also develops four flagella. We refer to these tiny cells as ***zoospores*** (*zoh*-uh-sporz) because they resemble one-celled animals. The zoospores burst out of the encasing mother cell and their flagella whip them through the water. When a zoospore reaches a favorable place, it grows into a holdfast cell. This holdfast cell divides into two new cells of which the upper one becomes an ordinary *Ulothrix* cell. This cell then forms a filament by further cell divisions.

At other times *Ulothrix* cells may undergo similar nuclear divisions and separation of the cell content into 8, 16, 32, or 64 bodies which are very similar to zoospores except that they are smaller and have only two flagella. These bodies are isogametes, and have definite sex even though they look alike. They leave the parent cell and swim away from the filament. If a gamete meets another gamete of the opposite sex, from another cell, they fuse and produce a zygote. After a rest period the zygote undergoes nuclear divisions resulting in four nuclei, as in *Spyrogyra.* In *Ulothrix,* however, all the nuclei live and, with a portion of the zygote protoplast, become zoospores. Each zoospore may produce a new holdfast cell and thus give rise to a new filament.

Life history of Oedogonium. *Oedogonium* (ee-doh-*goh*-nee-um) is a common green alga found in quiet pools, where it grows attached to rocks, sticks, and other objects. Like *Ulothrix,* the plant consists of an unbranched filament with a basal holdfast cell. Each cell has a single chloroplast composed of many joined strands. Pyrenoids are numerous (Fig. 20–5).

Any cell above the holdfast may convert its content into a large, single zoospore. The zoospore is propelled



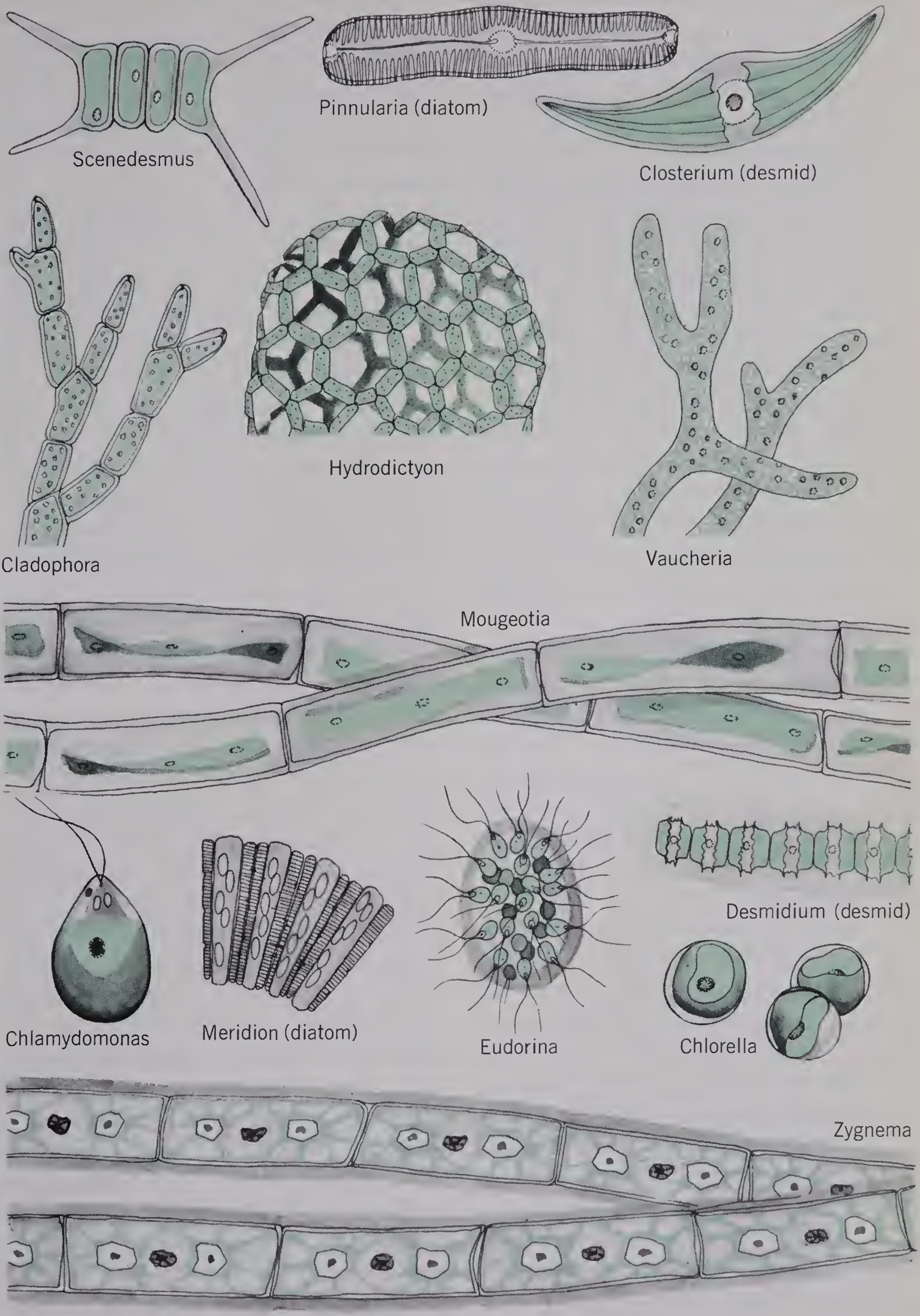
20-5 Sexual reproduction in *Oedogonium* involves heterogamy.

through the water by its ring of flagella. When a zoospore reaches a suitable location, it settles down and modifies to become a holdfast cell, thus establishing a new filament.

Sexual reproduction involves only certain cells in a filament of *Oedogonium*. In this way it is different from *Spirogyra* and *Ulothrix*. The protoplasts of special cells distributed along a filament each develops into a large, single egg. Each of these special cells is called an ***oogonium*** (oh-uh-*goh*-nee-um) and contains a tiny opening through its wall. In most species of *Oedogonium* two sperm develop in each of several shortened cells that form in groups in the filament. We refer to a sperm-producing cell as an ***antheridium***. A sperm looks like a miniature zoospore. Eggs and sperm may develop in the same or in different filaments, depending on the species of *Oedogonium*. Within a short time (often only a few minutes) after a sperm leaves an antheridium, it swims to the pore of an oogonium, enters, and fertilizes the egg. This produces a zygote. When the oogonium wall disintegrates some time later, the zygote escapes and undergoes a rest period. When conditions are again favorable for growth, the zygote forms four zoospores, which escape and establish new filaments of *Oedogonium*. *Oedogonium* is considered one of the more advanced algae because of its specialized heterogametes and because of the structural difference between the female gamete, or egg, and the male gamete, or sperm.

A closer look at the reproductive process in algae. In our study of certain fungi and *Spirogyra*, we noted the beginnings of sexual reproduction in the process of conjugation. In *Ulothrix* we have seen a further development in sexual reproduction, as gametes are formed that have definite sex although they look alike. In *Oedogonium*, gametes are formed that look distinctly different and are designated as sperm and egg. Remember that all these forms also undergo asexual reproduction by fission, fragmentation, or spore formation. Thus they have two ways to reproduce.

Now let us examine the sexual method more closely. In *Ulothrix*, for example, the isogametes, like all gametes, contain the haploid number of chromosomes. When two gametes fuse in the process of fertilization, the diploid number reappears in the zygote. This 2*n* zygote is the stage, or generation, in the life cycle referred to as the ***sporophyte***, because it produces spores. As


Scenedesmus
Pinnularia (diatom)
Closterium (desmid)
Cladophora
Hydrodictyon
Vaucheria
Mougeotia
Chlamydomonas
Meridion (diatom)
Eudorina
Desmidium (desmid)
Chlorella
Zygnema

20-6 Algae, though among the simplest plants, are represented by a rich variety of interesting forms.

we study the mosses, the ferns, and later the seed plants, we will find that this generation becomes increasingly prominent, until it is the only conspicuous part of the plant. In *Ulothrix*, however, it is present only in the form of the zygote. Soon after fertilization, the zygote undergoes a reduction division, resulting in two nuclei having the n number of chromosomes. This division is followed by a mitotic division, resulting in four haploid nuclei which become four zoospores. These give rise to new haploid *Ulothrix* filaments. Remember that the filament, as well as reproducing asexually, may at times produce gametes. For this reason it is known as the ***gametophyte*** (ge-*meet*-uh-fyt) generation and is the most conspicuous stage in *Ulothrix*. The gametophyte has the n number of chromosomes, as do the gametes produced from it by mitosis. The occurrence of two distinct stages in the life cycle is known as ***alternation of generations.*** You will discover as you study the evolution of plants that this alternation occurs throughout the plant kingdom, even though the relative importance of the generations varies.

Since alternation of generations occurs so generally, we can probably assume that it is of some advantage to the survival of the organism. Why might this be true? Think back to the fact that meiosis occurs in the zygote, or sporophyte generation. Meiosis allows for a reshuffling of the genes in chromosomes, so that the resulting haploid spores have various new combinations of genes not present in the parent. Some of these spores are probably better adapted than others to the environment in which they develop. Thus some of the spores have a survival advantage and continue to produce the species, while others die out. The haploid gametophyte (filament) that develops from the successful spores has the same survival advantages. These gene combinations are transmitted to the gametes intact, as the gametes are formed by mitosis.

At this point you might ask why meiosis occurs at all. If a successful combination of genes has been produced, how does it happen that they are again reshuffled? The answer probably lies in the fact that environments are constantly undergoing change of one kind or another. As these changes take place, various adaptations appear in the populations. Some are successful and some are not. Thus in alternation of generations, the sporophyte produces a variety of spores by meiosis. The gametophyte, on the other hand, transmits intact the more successful combinations of genes by mitosis. But the sporophyte stage still continues to supply new combinations as environmental conditions change.

Desmids. None of the green algae are more beautiful and fascinating to study than the group known as ***desmids.*** These free-floating algae may be either solitary or colonial; some form filaments. A desmid cell consists of two halves connected by a narrow isthmus in which the nucleus is situated. This unique structure makes them especially beautiful. You will find several desmids among the algae shown in Fig. 20–6.

Diatoms – very common algae in both fresh and salt water. The ***diatoms*** (*dy*-a-tahmz) belong to the phylum ***Chrysophyta*** (*kris*-o-fy-ta) and are one-celled, free-floating algae varying from rectangular, round, triangular, or oval to spindle-shaped or boat-shaped forms. They are sometimes green but more often golden brown. They all contain chlorophyll. The products of their photosynthesis are chiefly oils instead of carbohydrates. Diatoms are practically the only plants that grow in open seas, and next to the bacteria are the most numerous organisms in existence. Their walls contain small amounts of silicon dioxide and manganese. The wall is in two sections or valves, one fitting over the other like the top and bottom of a pillbox. One might say that the diatoms actually live in glass houses!

The shells of diatoms are pretty not only because of their shapes, but also because of the many fine lines that form intricate and beautiful designs on their walls. When they die, they fall to the bottom of the pond, stream, or ocean and may form deposits of diatomaceous earth. In California and other parts of the world, these deposits are thick. They are mined and sold as ingredients in various scouring powders, or used in filters in the refining of gasoline.

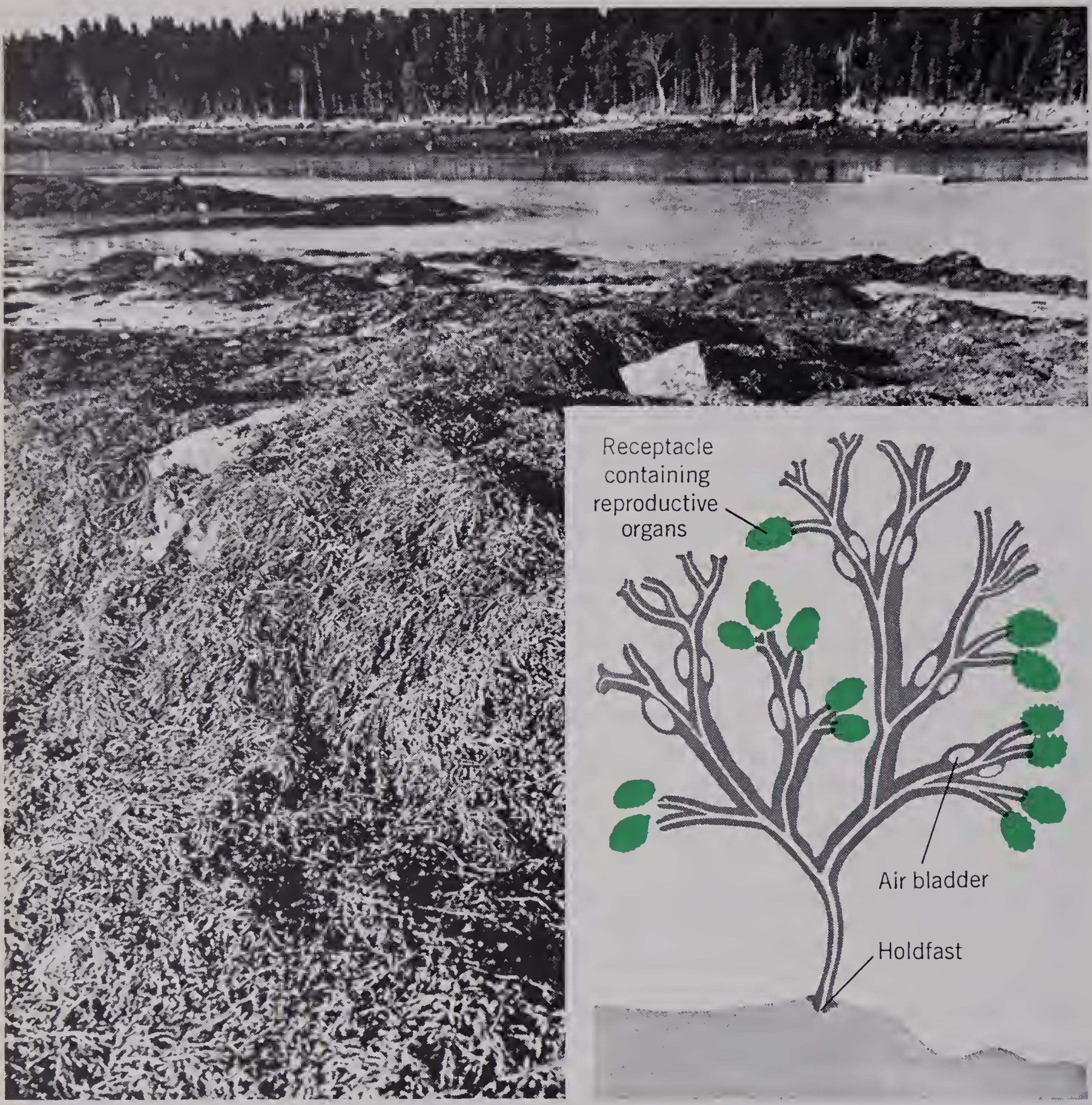
The dinoflagellates and cryptomonads. The phylum *Pyrrophyta* (pir-*ahf*-i-ta) is the smallest of the six algal phyla. The members are nearly all unicellular with two flagella, and live mostly in salt water, sometimes in fresh water. These organisms are of great importance as a source of food in the oceans. One of the genera, *Gymnodnium*, during certain times secretes a red pigment that is extremely toxic to fish. When this occurs fishermen speak of it as a "red tide." Why it occurs is a question that biologists have not yet been able to answer.

The red and brown algae. The ***brown algae*** belong to the phylum ***Phaeophyta*** (fay-*ahf*-i-ta) and the ***red algae*** to the phylum ***Rhodophyta*** (roh-*dahf*-i-ta). Both are mostly salt-water forms, better known as seaweeds. Sizes vary from some small threadlike red algae to the giant brown species of the Pacific Ocean, commonly called kelp. They usually live in shallow water near the shore, where light can reach them, but some of the reds live in deeper water. These red algae grow attached to solid objects on the bottom or may grow in mud or sand. Because they vary so much in structure and reproduction and are often difficult to obtain, we cannot study any one type. A brown alga called *Fucus* is a favorite for study because it is so common along the seacoast (Fig. 20–7). You may find it as the packing around oysters, lobsters, and other seafoods that are shipped from the coast to your town.

Economic importance of the algae. Algae are the chief source of food and energy for much of the animal life in the environments in which they occur. Although many small fish live entirely on algae, one large group of mammals, the whales, also exists primarily on them. As we said at the beginning of this chapter, algae are also a source of oxygen for aquatic animal life.

The use of marine algae as soil fertilizers has long been known. If seaweeds are mixed with the soil, they not only add organic matter to it but also replenish the mineral salts that land-growing plants have removed. Algae are particularly rich in iodine, a chemical element essential to plant and animal life.

While algae are useful in certain parts of the world in the preparation of soups, gelatins, and other foods, we are more likely to find them as a part of our ice cream. A sodium compound extracted from algae is added to keep the ice cream smooth. This compound may also be used as a stabilizer in chocolate milk or as a thickener in salad dressings. *Agar-agar* (*ahg*-ahr-*ahg*-ahr)



20-7 *Fucus* is a brown alga that inhabits rocks at the water line along the Atlantic Coast. At low tide, it covers the rocks and at high tide is under water. (Walter Dawn)

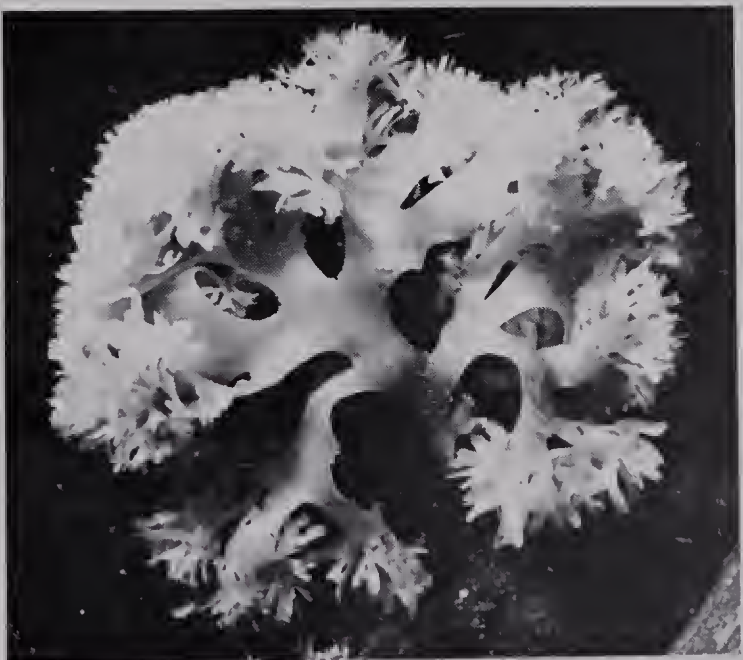
is produced from red algae in the Indian Ocean and is used in hospitals and laboratories as a base for culture medium for bacteria. The list of other industrial uses of algal preparations ranges from cosmetics to leather-finishing.

An interesting new discovery is that algae can be mass-cultured in plastic tubes or tanks. By supplying the culture with all the best conditions for photosynthesis, such as light, water, and carbon dioxide, the algae multiply rapidly. Periodically some algae are strained out, dried, and then made ready for use as flour in baking or as a thickening in foods such as soup.

Some algae may become poisonous when they die, and thus pollute the water. This not only makes the water unfit for human beings, but also for fish and other water life. Great care is taken in fish hatcheries to prevent this. A very weak solution of copper sulfate put in the water will kill blue-green algae. This treatment, however, is not recommended for home aquaria because there is considerable danger of overdosing, which would kill the fish.

Use of algae in space flights. One of the problems that must be solved before man can make long trips in space is that of disposing of the waste product of man's respiration, carbon dioxide. Recent research indicates that certain forms of algae may be useful in accomplishing this purification of the air in a space ship. Algae, like all organisms containing chlorophyll, use carbon dioxide and give off oxygen as a waste product in the process of photosynthesis. There are certain hot-climate algae that reproduce faster than cold-climate types. They are, in fact, capable of multiplying a thousand-fold in 24 hours. These types, of course, use up carbon dioxide and produce oxygen faster than ordinary types. It is therefore believed that they might be effective both for purifying the air in a space ship and for supplying some of the oxygen needs.

Food is also a problem in space travel. *Chlorella* is being considered as a possible food source. Mice have been fed these algae, and it is believed that they would be suitable for human use in a space capsule. In one hour a *Chlorella* cell can produce 18 grams (dry weight) of food. Nitrogen is necessary for protein synthesis in algae as in all living things. It has been found that algae can utilize the nitrogen present in human urine to fulfill this need.

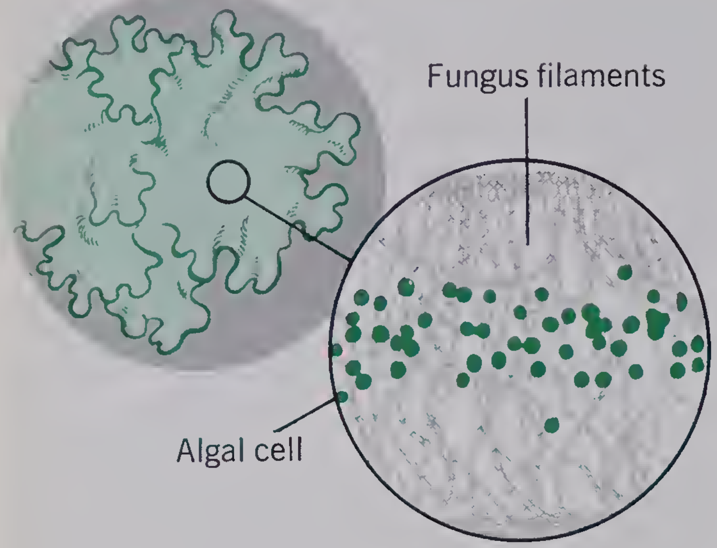


20-8 *Chondrus crispus,* also called Irish moss, is a marine red alga. It grows on rocks along the cold North Atlantic Coast. (Hugh Spencer)

20-9 These kelp are brown algae which live on the bottom of the Pacific Ocean but in sufficiently shallow water so that light can reach them. (Cadbury from National Audubon Society)

Lichens, curious plant relationships. While ***lichens*** (*ly*-kenz) are often grouped with the fungi, they can also be placed with the algae, because an alga and a fungus make up the plant body of a lichen. While various lichens differ in structure, the alga is usually a green or blue-green form while the fungus is one of the Ascomycetes.

The plant body of a lichen consists of a mass of fungus hyphae among which the algal cells are scattered. Lichens are of three general types. Some form a hard, granular crust (*crustose lichens*). Others resemble flattened, leathery leaves (*foliose lichens*).



20-10 A lichen is actually two kinds of plants living together by symbiosis, or mutual benefit. Here is a green alga living among fungal cells, the two combined making up the lichen plant body.

Still others form a network of slender branches (*fruticose lichens*).

In a lichen both the alga and the fungus benefit from the association. In fact, neither could survive alone in the environments where lichens live. The fungus depends on the alga for food, produced by photosynthesis. Although the alga is in a sense a "slave", it is protected and kept moist by the fungus hyphae. This relationship, in which two organisms live together for the mutual good of each, is *symbiosis*.

The biological teamwork illustrated in a lichen allows it to live in places where few other plants can survive. Many lichens grow on tree trunks. Others cling to rock surfaces far above timber line in the alpine zone of high mountains. These lichens are important pioneer plants. Gradually they cause rock surfaces to crumble and, as they add their own remains season after season, produce organic matter that is the basis for soil. This soil can then support other plants.

Lichens are among the most abundant plants of the wind-swept areas of the Far North. One of these lichens, *Cladonia*, is so valuable as food for reindeer that it is commonly called *reindeer moss*.

IN CONCLUSION

Algae are among the most important protists. They are vital in water environments as food for the animals there and as a source of oxygen.

Algae range from single-celled to many-celled forms and reproduce by simple fission, thus forming new unicellular plants or adding to the size of colonies of cells. Many algae also reproduce asexually by forming zoospores, which swim about and form new plants directly when they germinate. Sexual reproduction also occurs and involves isogametes or heterogametes.

BIOLOGICALLY SPEAKING

alternation of generations
antheridium
apical cell
Chlorophyta
Chrysophyta
concave cell
Cyanophyta
filament
fragmentation
gametophyte
heterocyst
holdfast
matrix
oogonium
Phaeophyta
phycocyanin
pyrenoid
Pyrrophyta
Rhodophyta
sporophyte
zoospore

QUESTIONS FOR REVIEW

1. How are the algae fundamentally different from the fungi?
2. In what respect are the algae simpler in structure than higher plants?
3. Explain how colonies of algae increase in size during the growing season.
4. Name six phyla of algae and give an example of each.
5. Why are blue-green algae an especially serious problem in a community water supply?
6. Account for the color of blue-green algae.
7. Describe a heterocyst of *Nostoc* or *Anabaena,* and explain how it causes filaments to break up.
8. Describe the composition of a ball of *Nostoc.*
9. Account for the slimy texture of *Gloeocapsa.*
10. What characteristic of *Oscillatoria* is referred to in its name?
11. What pigments other than chlorophyll are present in the cells of green algae?
12. Describe the habitat of *Protococcus.*
13. Why is *Chlorella* of special interest to biologists?
14. How can you easily distinguish *Spirogyra* from other filamentous green algae under the microscope?
15. Describe conjugation in *Spirogyra.*
16. How can you distinguish a *Ulothrix* spore from a gamete?
17. What is alternation of generations? Describe its occurrence in *Ulothrix.*
18. What characteristics distinguish diatoms from other algae?
19. What are some uses for diatomaceous earth?
20. Describe the typical habitat of red and brown algae.
21. List some of the reasons why algae are economically important.
22. How does a lichen show symbiosis?

APPLYING PRINCIPLES AND CONCEPTS

1. What evidence can you give that all algae contain chlorophyll even though many are not green?
2. A colony of 50 algal cells is not a 50-celled plant. Explain why.
3. Both spores and gametes are reproductive cells. How are they different?
4. In what respect are the cells of blue-green algae more primitive than those of green algae?
5. Why is conjugation in *Spirogyra* considered a primitive form of sexual reproduction?
6. In what ways is sexual reproduction in *Oedogonium* more efficient and more advanced than the sexual reproduction in *Ulothrix?*
7. Compare *Spirogyra, Ulothrix,* and *Oedogonium* in regard to specialization of cells in a filament.
8. What is believed to be the significance of sexual reproduction in plant evolution?

RELATED READING

Books

Alexopoulos, C. J. *Introductory Mycology*, 2nd Ed. John Wiley and Sons, Inc., New York. 1962

Boettcher, Helmuth M. *Wonder Drugs: A History of Antibiotics*. J. B. Lippincott Co., Philadelphia. 1964

Clark, Paul F. *Pioneer Microbiologists of America*. The University of Wisconsin Press, Madison. 1961

Duddington, Charles L. *Micro-organisms as Allies: The Industrial Use of Fungi and Bacteria*. The Macmillan Co., Chicago. 1961

Fink, B. *The Lichen Flora of the United States*. University of Michigan Press, Ann Arbor. 1960

Fraenkel-Conrat, Heinze. *Design and Function at the Threshold of Life: The Viruses*. Academic Press, Inc., New York. 1962

Glasschiek, H. S., M.D. *The March of Medicine: The Emergence and Triumph of Modern Medicine*. G. P. Putnam's Sons, New York. 1964

Hardy, Alister C. *The Open Sea, Its Natural History: The World of Plankton*. Houghton Mifflin, Boston. 1956

Kalver, Lucy. *The Wonders of Algae*. John Day Co., New York. 1961

Kalver, Lucy. *The Wonders of Fungi*. John Day Co., New York. 1964

Kleijn, H. *Mushrooms and Other Fungi*. Doubleday and Co., Garden City, N.Y. 1962

Landon, John F. and Sider, Helen T. *Communicable Diseases*. F. A. Davis Co., Philadelphia. 1964

Low, Robert Cranston. *Atlas of Bacteriology*, 2nd Ed. Williams and Wilkins Co., Baltimore. 1964

Prescott, Gerald W. *How to Know the Fresh-Water Algae*. Wm. C. Brown Co., Dubuque, Iowa. 1954

Prescott, Samuel Cate. *Industrial Microbiology*, 3rd Ed. McGraw-Hill Book Co., New York. 1959

Riedman, Sarah R. *Portraits of Nobel Laureates in Medicine and Physiology*. Abelard- Schuman, Ltd., New York. 1964

Riedman, Sarah R. *Shots Without Guns: The Story of Vaccination*. Rand McNally & Co., Chicago. 1960

Smith, Gilbert M. *The Fresh-Water Algae of the United States*. McGraw-Hill Book Co., New York. 1950

Stanier, Roger Y. *The Microbial World*. Prentice-Hall, Inc., Englewood Cliffs. N.J. 1963

Stanley, Wendell M. and Evans, G. Valens. *Viruses and the Nature of Life*. E. P. Dutton and Co., New York. 1961

Starobinski, Jean. *A History of Medicine*. Hawthorn Books, Inc., New York. 1964

Tiffany, Louis. *Algae: The Grass of Many Waters*. Charles C. Thomas, Springfield, Ill. 1958

Wyss, Orville and Williams, O. B. *Elementary Microbiology*. John Wiley and Sons, Inc., New York. 1963.

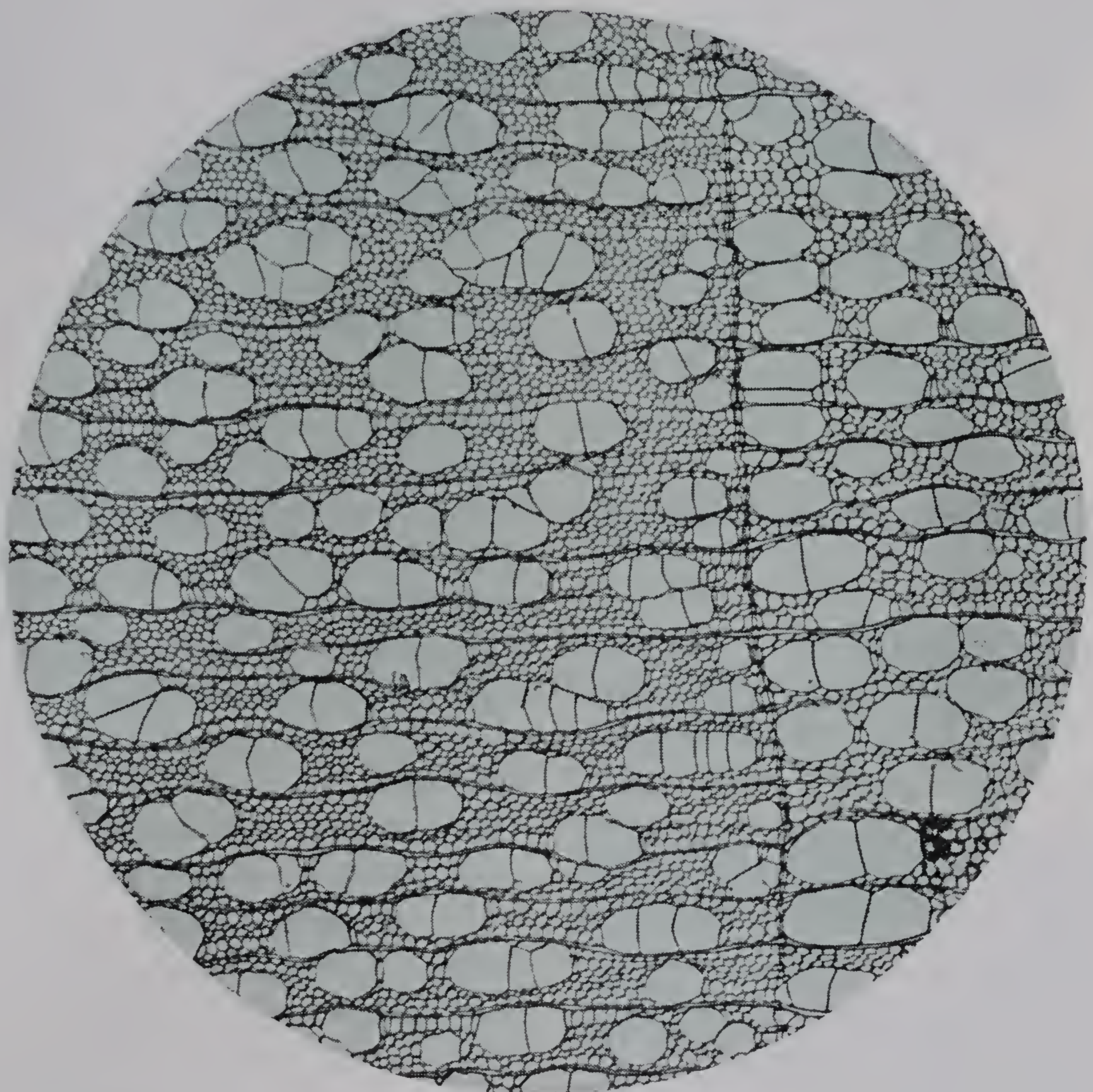
Articles

Burnet, Sir MacFarlane. "Viruses." *Scientific American*. May, 1951

Palmer, C. Mervin. *Algae in Water Supplies*, an illustrated manual on identification, Public Health Service Bulletin, Number 657. The Supt. of Documents, Washington, D.C. 1959

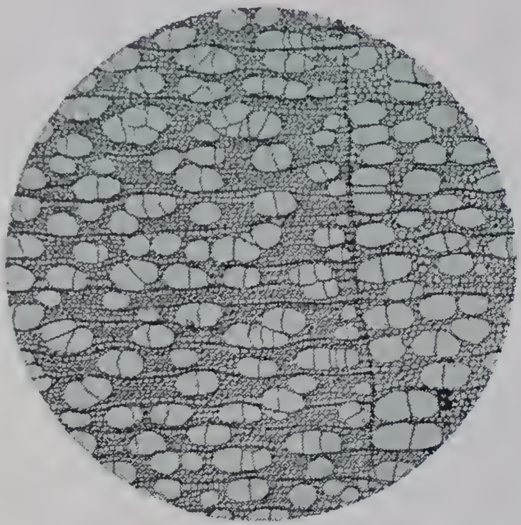
UNIT FOUR

MULTICELLULAR PLANTS



Ages ago, modifications probably occurred in certain aquatic plants which allowed them to invade a new environment — the land. Perhaps some ancestral alga growing on moist soil developed an aerial shoot from a filamentous plant body and extended root-like projections into the soil. The mosses are perhaps remnants of these first land plants. However, they never became fully adapted to a terrestrial environment. It remained for the seed plants, with vascular tissues for conduction and support, and seeds to protect and nourish the embryo plant, to dominate the land environments of the earth.

CHAPTER 21



MOSSES AND FERNS

The great kingdom Plantae. The plant kingdom includes the mosses and ferns and their allies, and all the seed plants. The many kinds of mosses belong to the phylum ***Bryophyta*** (bry-*ahf*-i-ta), but all the other members of this kingdom are placed in the phylum ***Tracheophyta*** (tray-kee-*ahf*-i-ta). This is because of the fact that they have organized tissues for conducting food and water through the plant. Such tissue is called ***vascular tissue.*** Although the mosses and ferns are classified in two separate phyla, we shall study them together because they are both comparatively simple land plants which differ greatly from the seed plants. In addition, their reproductive cycles are similar, and studied together the mosses and ferns provide an interesting evolutionary picture of the transition to land life.

The Bryophyta. The bryophytes consist of two main groups of plants, the mosses and the liverworts. They are found in every region of the world from the high mountains of the Antarctic through the tropics of northern Greenland. They thrive equally well in the coldest climates or the warmest. Although their preferred habitats are chiefly terrestrial, they all require an abundance of moisture; some even live in hot springs. Early in the Paleozoic era they were probably mostly aquatic, but gradually they became adapted to the land. Perhaps they were the first plants to live exclusively on land.

No bryophyte plant body is very large. Although they live on land, these plants lack structures for efficient conduction of water to the leaves. Nor do they have true roots, so they cannot absorb water except from the surface of the soil. Thus, the bryophytes, while showing a more complicated reproductive cycle than the algae, do not have cell specialization for water movement on a large scale. Such specialization is necessary for a large plant to live successfully on land.

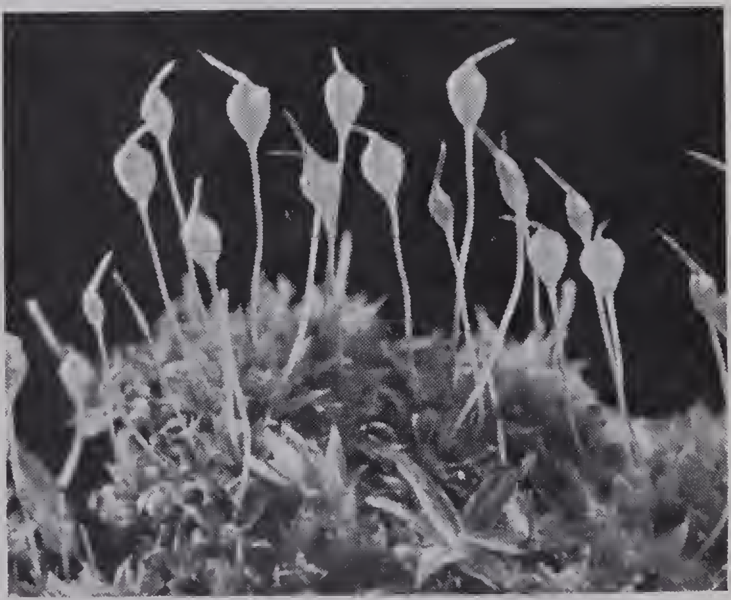
The mosses. You have seen mosses growing in cracks in shaded sidewalks, on moist ground under trees, or in clumps in deep woods. What looks like a tuft or carpet is actually a compact clump of moss plants. Each plant has its tiny "stem" with a cluster of "leaves" encircling it. If you pull one of these tiny plants from the soil, you will find a group of hairlike ***rhizoids*** (*ry*-zoidz) growing from the base of the stem. Mosses do not have true roots containing conducting tissues, as do higher plants, but the rhizoids serve a purpose by anchoring the plant and by absorbing some water and dissolved minerals from the soil. Mosses do, however, have structures that resemble the leaves and stems found in higher plants.

21-1 Mosses, shown here with two mushrooms, are well adapted to moist woodland environments. (Walter Dawn)

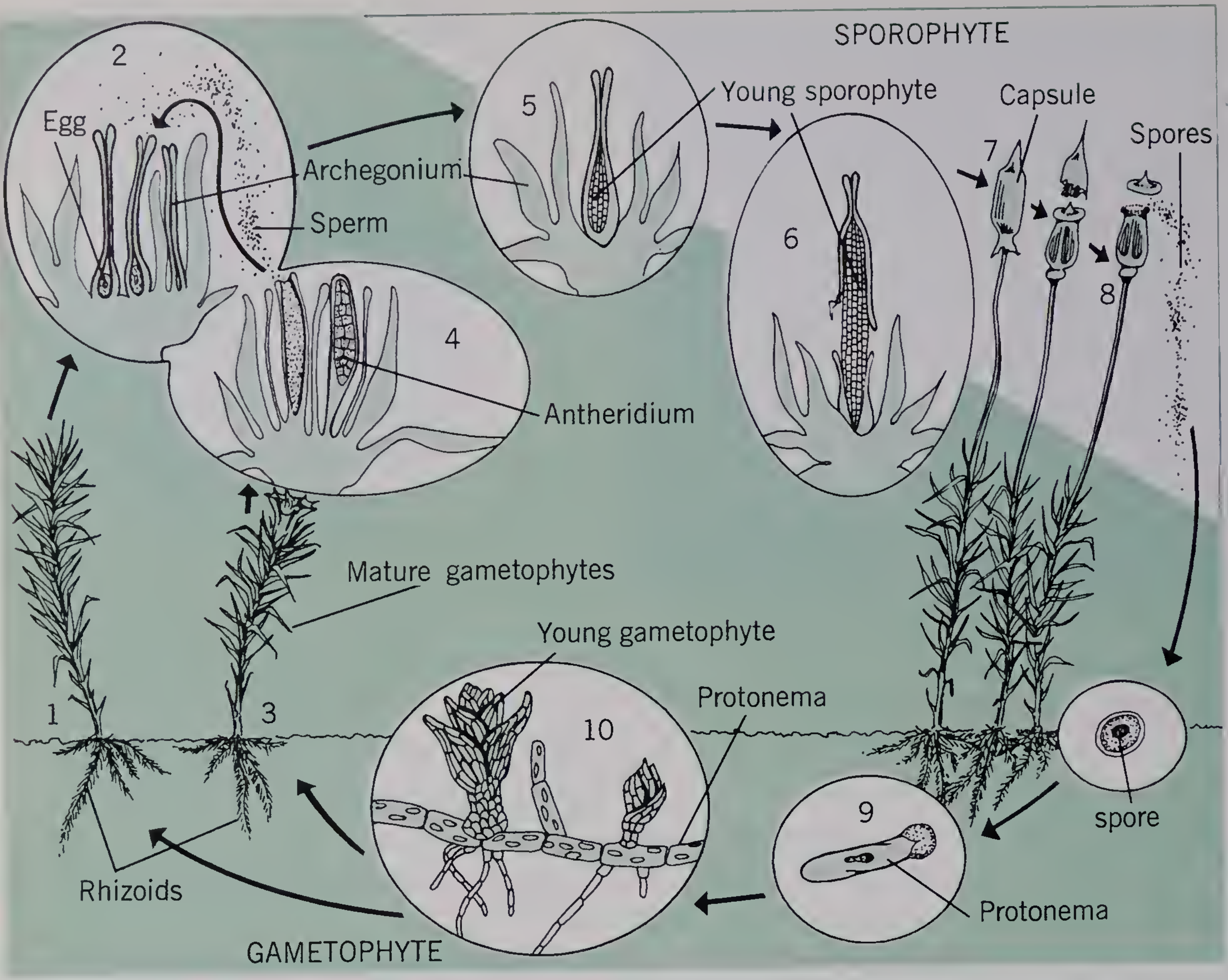
Life cycle of the moss. The moss plant we commonly see is only one phase of the life cycle. If you examine the diagram in Fig. 21–3, you will see that each moss plant goes through a reproductive cycle in which an asexual spore-producing stage forms a sexual gamete-producing stage. This in turn forms the spore stage again. You will recognize this as the alternation of generations we discussed in the last chapter.

Sexual reproductive organs develop at the tips of the leafy stems of gametophyte moss plants, in clusters hidden by leaves. Depending on the species of moss, male and female organs may be borne on the same plant, on different branches of the same plant, or on separate plants. Sperm are formed in club-shaped, short-stalked ***antheridia.*** A cap at the apex of the antheridium opens at maturity, allowing the sperm to escape. The female organs, or ***archegonia*** (ahr-ki-*goh*-nee-a), are borne on short stalks. A swollen base contains a single egg. Sperm swim to the archegonium after a rain or even in a film of dew, but they cannot move unless there is some water present. A sperm passes through the neck of the archegonium and fertilizes the egg. This union results in the zygote.

Fertilization starts the sporophyte, or asexual phase, of the cycle. The zygote always remains in the female organ. Soon the sporophyte begins to grow and produces a slender stalk that grows up and out of the leafy stem of the plant. The top of the stalk swells and becomes a large mass of tissue called a ***capsule,*** which is covered with a thin hood. Inside the capsule there are formed many microscopic ***spores.*** These are asexual. That is, they are neither definitely male nor female. When the spores are ripe, the hood falls off, the capsule opens, and the spores escape. They are carried off by the wind, and when they fall on the ground they begin to grow, provided environmental conditions are right. The sporophyte stage has ended, and the gametophyte stage begins. Notice that the spores are dis-



21-2 In this cluster of moss plants note the capsules on their slender stalks. This is the sporophyte stage. You can also see the leafy gametophyte stage from which the sporophyte grows. Inside the capsules are the sporangia with their spores, ready to be discharged when the capsule bursts open. (Hugh Spencer)


SPOROPHYTE
2
Egg
Archegonium
Sperm
5
Young sporophyte
Capsule
Spores
7
6
8
4
Antheridium
Mature gametophytes
Young gametophyte
1
3
10
Protonema
9
spore
Rhizoids
Protonema
GAMETOPHYTE

21-3 Life cycle of the moss. Note in stages 1 and 2 the female gametophyte and in 3 and 4 the male gametophyte plants. After fertilization, the sporophyte generation (stages 5, 6, and 7) grows out of the top of the female plant. Spores form in the sporangia inside the capsule at the top of the sporophyte (stage 8) and when mature fall to the ground and give rise to a new generation of gametophyte plants (stages 9 and 10).

persed without the aid of water, while the gametes still depend on water for fertilization.

Recall that in the algae heterogamy developed slowly but occurred in a water environment. As the mosses evolved and became adapted to dry land, the sporophyte generation was able to exist in the new type of habitat. The gametophyte generation, however, still required water for the sperm to reach the egg. We shall observe this evolutionary process in the various groups of higher plants.

Each spore produces a small thread-like structure called a ***protonema*** (proht-o-*nee*-ma). All the cells that make up the protonema have chlorophyll and can make their own food. The resemblance of the protonema to an alga is startling and once caused many scientists to class it as a close relative of the algae. Some cells of the protonema produce short buds that grow into a new moss plant. Other threads enter the ground and become the rhizoids. Thus, a new moss plant is formed and this gametophyte will soon form sex cells.

In the moss life cycle, the sporophyte is diploid, having the $2n$ number of chromosomes. Meiosis occurs in the sporophyte, and haploid (n) spores are produced. The haploid gametophyte grows from the spore and produces hap-

21-4 Sphagnum, or peat moss, is a valuable mulch for gardens and lawns. It is also used for packing delicate and fragile flowers for shipment. (Hugh Spencer)

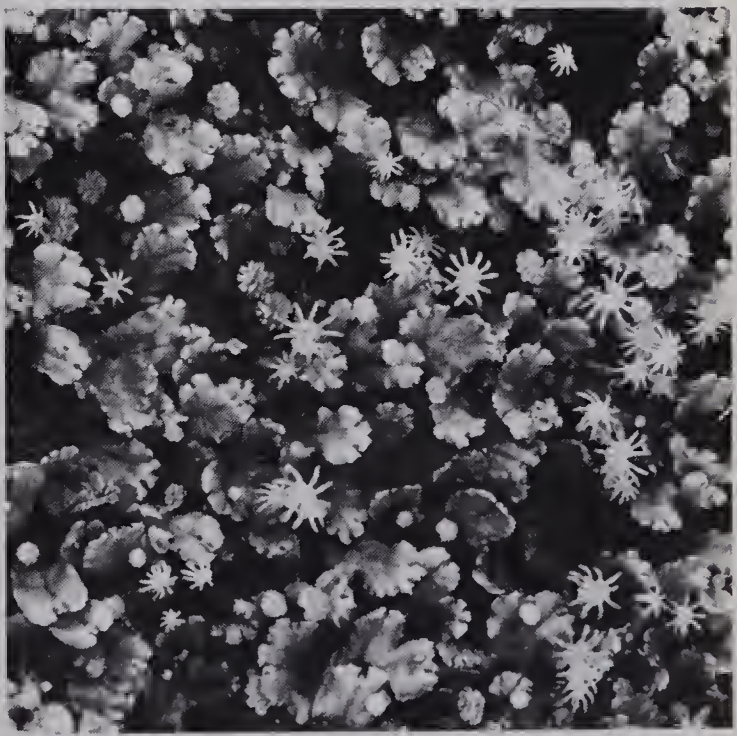
loid gametes. Fertilization restores the diploid number of chromosomes to the zygote.

Economic importance of the mosses. The *sphagnum*, or peat-forming mosses, are the most widely used. Sphagnum grows in small lakes and bogs, where it forms floating mats. These mats increase in size and thickness each year as generation after generation occupies the surface of the mat. Plants of previous years decompose slowly, settle to the bottom, and form *peat*. In time the growth of sphagnum mats in a lake may close the water entirely, causing the lake to enter the bog stage. Eventually what was once an open lake may become a deep deposit of brownish-black peat. Large sphagnum mats are often invaded by larger plants — rushes, grasses, shrubs, and even trees.

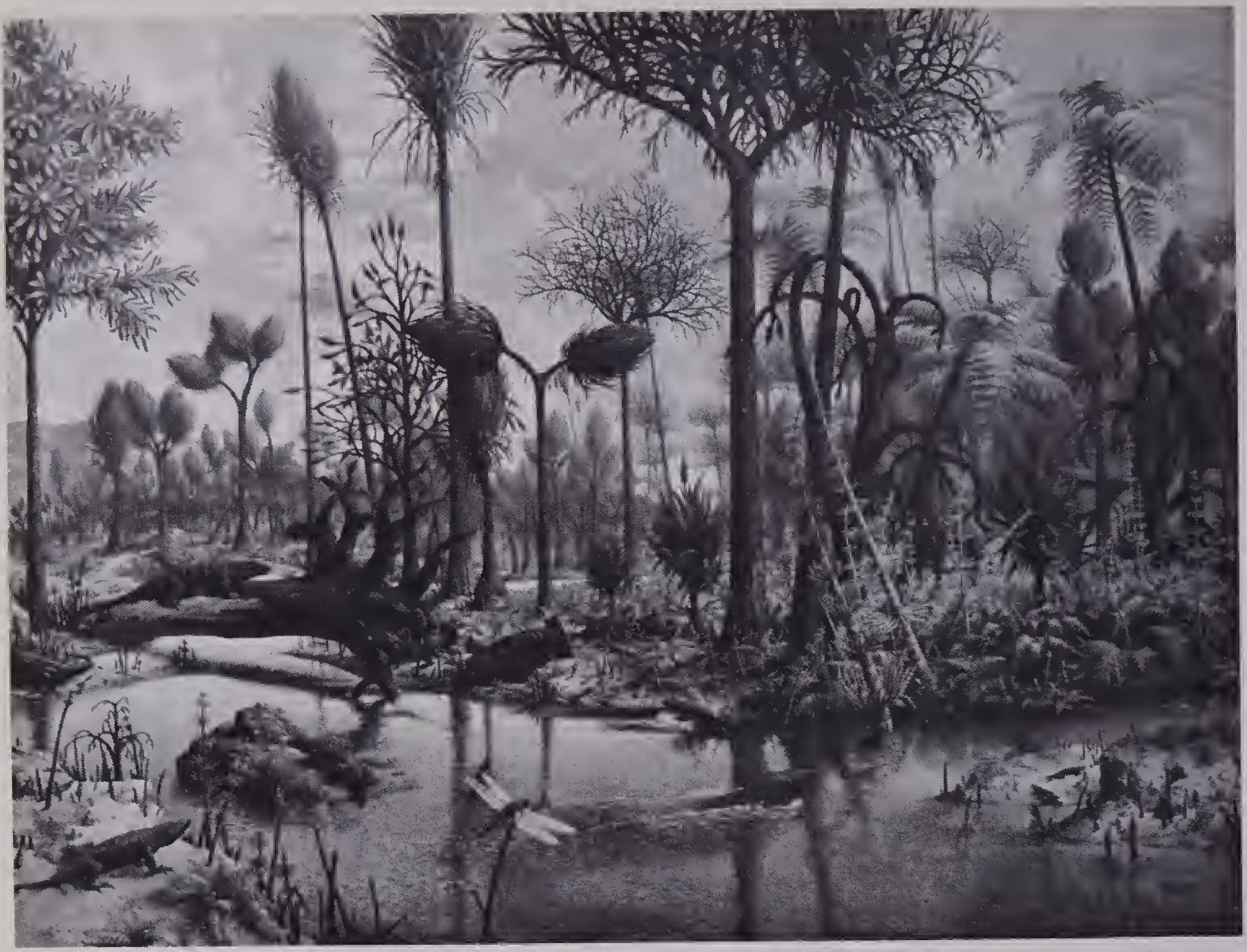
The absorbent quality of sphagnum makes it valuable to the gardener as a *mulch*. It can be worked into the soil or placed on the surface to make the soil loose and to hold water during the usually dry summer months.

Other mosses are important to us as pioneer plants in rocky areas. The small amount of soil that collects in cracks on the bare surfaces of cliffs and ledges is sufficient to support moss plants. The rhizoids break down rocks gradually and thus form more soil. As mosses die and decompose season after season, they form enough soil to anchor the roots of larger plants.

The liverworts. Much less familiar than mosses are their relatives, the liverworts. These curious small plants grow in wet places, often along the banks of streams, around the outlet of a spring, on rocky ledges or in the water. The moist soil and flowerpots in greenhouses are other good places to find liverworts. They look like thin, leathery leaves laid flat against the ground. One of the com-



21-5 In this photograph of the liverwort *Marchantia,* the antheridia are found embedded in the club-shaped disks. The archegonia occur embedded in the star-shaped structures. The "leaves" are merely lobed disks which resemble a liver except that they are green. (Carolina Biological Supply House)



21-6 During the Pennsylvanian and Mississippian periods (about 300 million years ago) a typical forest contained giant spore-bearing plants, some of which have been redrawn in this picture from their fossil remains. (Yale Peabody Museum)

mon liverworts resembles a thin tongue with Y-shaped branches at the tip. Under ideal conditions a clump of liverworts may cover a considerable area. Figure 21–5 shows a common liverwort, *Marchantia* (mar-*kan*-shee-a). The female sex organs are formed in curious structures like umbrellas, which rise about an inch above the flat plant body. Male sex organs form in disk-shaped structures.

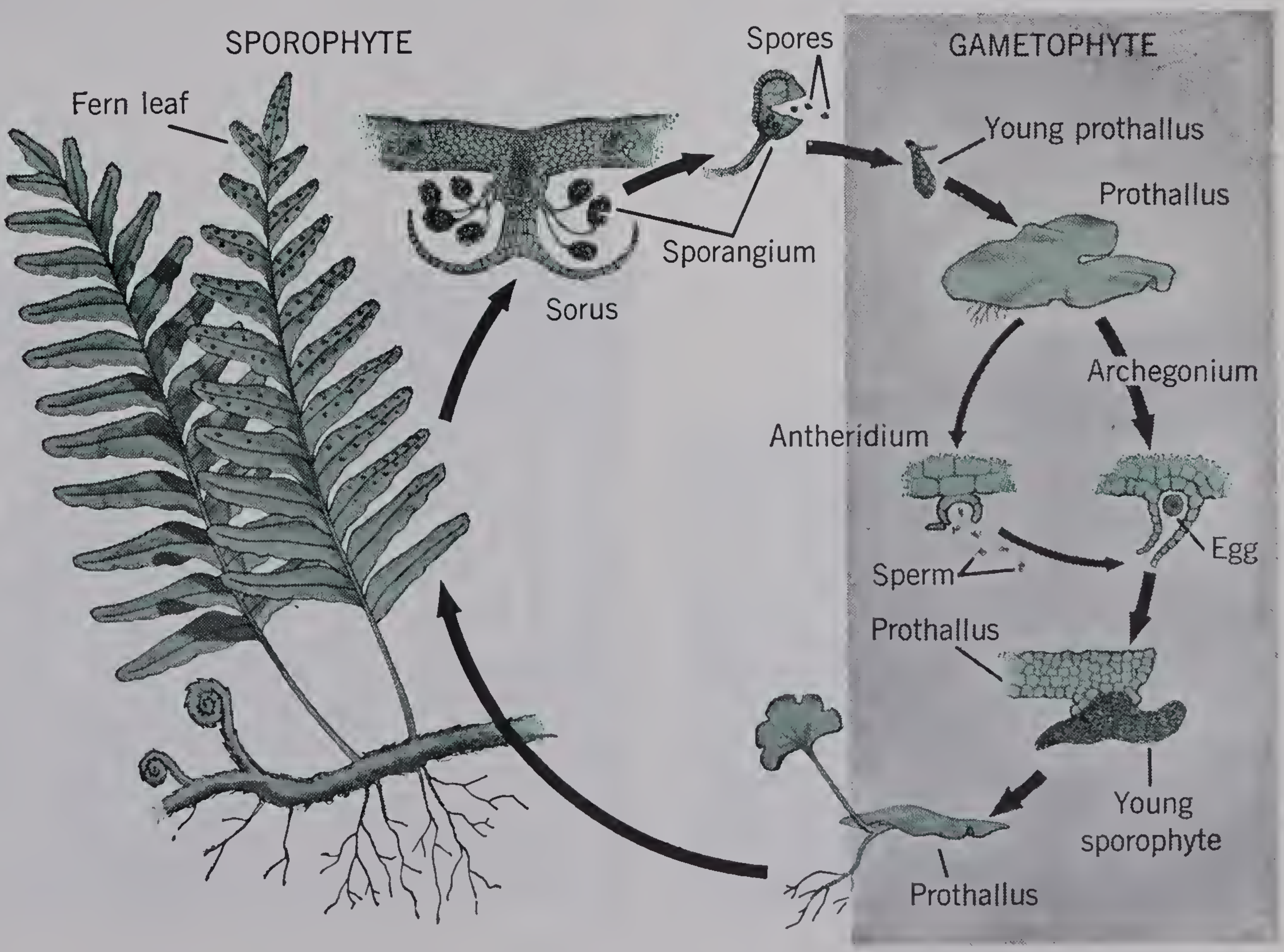
The Tracheophyta — vascular plants. As you have already learned, all the tracheophytes possess tissues for conducting food and water through the plant. In this chapter we are concerned only with one group of this large phylum — the ferns and their allies. To appreciate this group fully, we should have lived about 300 million years ago during the ***Carboniferous period,*** which includes the Pennsylvanian and Mississippian periods combined. Then they were not limited to a few places in the woods or swamps, some hillsides, and flowerpots. They formed large forests that covered the wet, marshy land common at that time. Ferns much like those of today flourished during this past age, but tree ferns 30 to 40 feet high were also abundant.

Although no man ever saw those great forests of ferns, today we are reaping the benefits of their existence. During this age, deep layers of plant remains accumulated in the swampy areas where they grew. Later the movements of the earth compressed these layers into layers of coal. It has been estimated that it took 300 feet of compressed vegetation to form 20 feet of coal. When we consider what coal has meant to industry and living, we might almost conclude that the high civilization of modern America has sprung from the vegetation of millions of years ago.

Most of us are familiar with ferns as clumps of plants with graceful, deeply-cut leaves. In all but the few remaining tree ferns of the tropics, the stems are underground, creeping horizontally just below the surface. These underground stems, which are called ***rhizomes*** (ry-zohmz), bear clusters of true roots that spread through the ground, anchoring the plant and absorbing water and dissolved minerals.

Life cycle of the fern. The fern you find in the shaded woods or growing as a potted plant is the sporophyte stage of the life cycle (Fig. 21–7). As in the mosses it is diploid ($2n$). When the familiar fern leaves are mature, small dots called ***sori*** appear on the lower side. The sori differ in shape and location in different kinds of ferns. Some people become alarmed when sori appear and remove them carefully, mistakenly thinking the fern is diseased.

Each sorus consists of a cluster of helmet-shaped ***sporangia***, each of which contains numerous spores. These are the result of meiosis, as they are in the mosses, and are haploid. The sporangium is attached to the sorus by a short



21-7 The life cycle of the fern. Note the sori on the fern frond. These contain the sporangia. The gametophyte generation develops on the ground and is so small you can hardly see it.

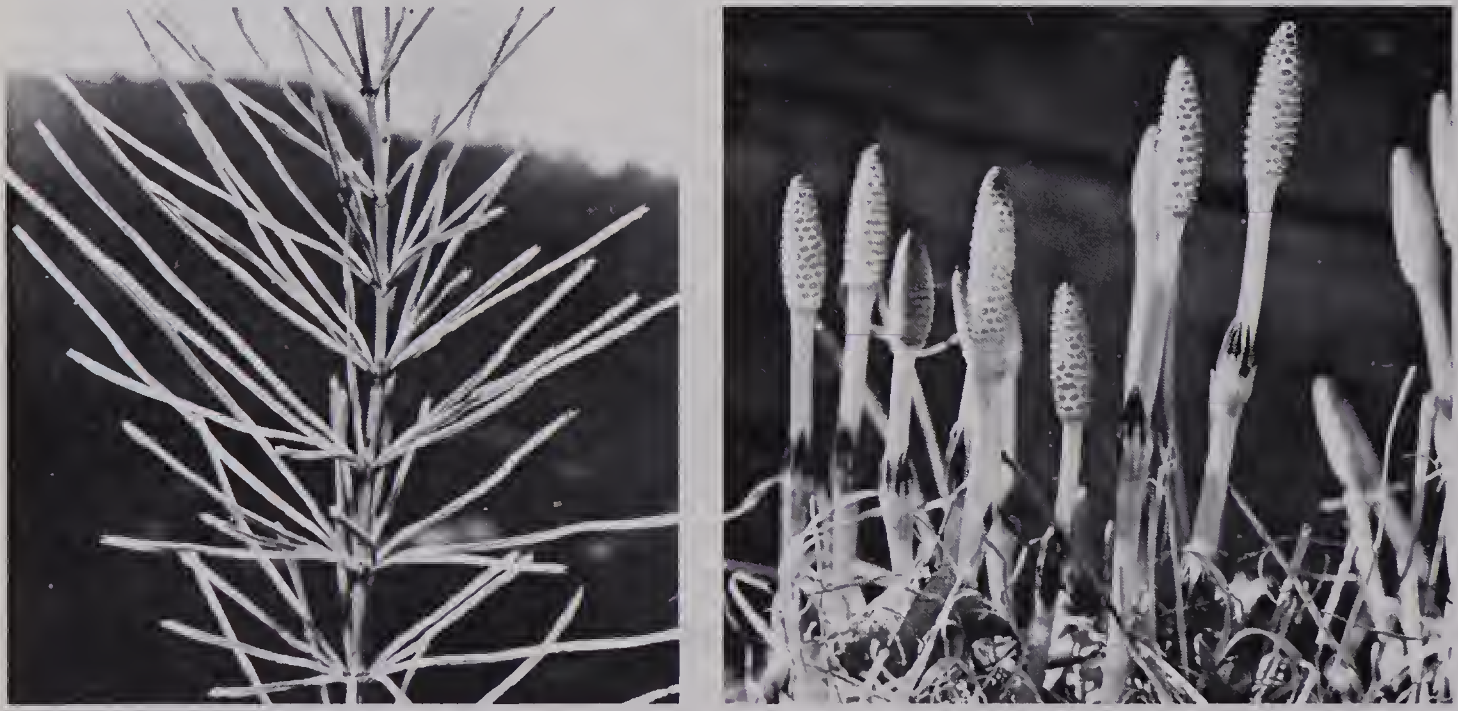
stalk. Since the fern plant bears sporangia and spores, it corresponds to the stalk and capsule of the moss.

When the spores are mature, the sporangium bursts open and releases them. The tiny spores are easily picked up by the wind and carried to new locations. If a spore falls in a moist place, it germinates and grows into a short filament of cells with rhizoids. The gametophyte stage of the fern life cycle has begun. This stage at first resembles the protonema of a moss. However, unlike the moss, the filament broadens at the tip and becomes a flat, heart-shaped structure called a ***prothallium.*** When fully grown, the prothallium may be a quarter to a half inch in diameter. The flat prothallium is green and clings close to the ground, held by a cluster of rhizoids that forms on the underside at the rounded or lower end of the "heart." It would be an interesting project for you to try to raise some fern prothallia.

Several antheridia containing sperm develop among the rhizoids. A number of archegonia form near the notch at the upper end of the prothallium. Each one contains an egg. In most ferns the eggs and sperm mature at different times. Thus, when sperm escape, they swim in the film of dew to another prothallium. Thus both mosses and ferns, while largely land plants, still require water for fertilization. When a sperm fertilizes an egg, a diploid zygote is produced. This marks the end of the gametophyte stage and the beginning of the sporophyte stage. It is interesting to note that this prothallium stage of a fern corresponds to the leafy-shoot stage of the moss.

Immediately after fertilization the zygote grows into a young fern plant. Soon the young fern becomes established with a root, a leaf, or ***frond,*** and a stem. The stem bears additional fronds and the familiar fern clump results. Thus the sporophyte is the most conspicuous part of the life cycle of the fern.

In comparing the life cycle of the fern with that of the moss, you will see



21-8 The horsetail rush produces bushy, green vegetative shoots (left) and brownish, cone-like structures which bear the reproductive organs. Note the scale-like leaves which appear in whorls on the stem. (Left: Walter Dawn; right: Hugh Spencer)

21-9 Club mosses are closely related to the ferns because their methods of reproduction are similar. Because they are evergreen and look like the leaves of fir and spruce trees, they are picked for Christmas decorations and therefore are rapidly becoming extinct. (Walter Dawn)

that the gametophyte generation is relatively insignificant. The sporophyte generation has become the dominant phase of the plant. This is also true in the seed plants, which you will study in the following chapters.

Relatives of the fern. Closely related to the ferns are two groups of plants, fairly common in some localities. The *equisetums* (ek-we-*seet*-umz), or *horsetail rushes*, are often seen in wet places or around the margins of lakes. The reproductive stems are slender, dark green, and rodlike, and bear light-colored cones at their tips. There are also green, bushy stems that give the plant its name. The leaves are small scale-like structures occurring in circles around the stem at regular intervals.

Club mosses resemble true mosses only in general appearance and constitute another group of the fern relatives. These plants bear cone-like reproductive structures at the tops of certain of their branches (Fig. 21–9). Various species are found in rich, damp woods, or creeping along the rocky slopes of mountains. Some species even occur in deserts. Like the ferns, both horsetails and club mosses are now merely remnants of plant groups that were once more abundant. In prehistoric times they were the size of present-day trees. You can still see their remains in the form of leaf or stem imprints in coal.

IN CONCLUSION

The two plant groups that are forerunners of the seed plants are the mosses and the ferns. They both show a complicated life cycle in which one spore-producing stage, the sporophyte, produces a gamete-producing stage, the gametophyte, in an alternation of generations. These plants once covered the earth, and millions of years ago with the remains of other plants, formed the coal we use today.

Our survey of the plant kingdom thus far has shown us the simpler, flowerless, less-noticed forms of plant life. In the next chapter we will discuss the great group of seed-bearing plants. They too are an important and interesting collection of living organisms.

BIOLOGICALLY SPEAKING

antheridium
archegonium
Bryophyta
capsule
Carboniferous period
frond
prothallium
protonema
rhizoid
rhizome
sorus
sporangium
spore
Tracheophyta
vascular tissue

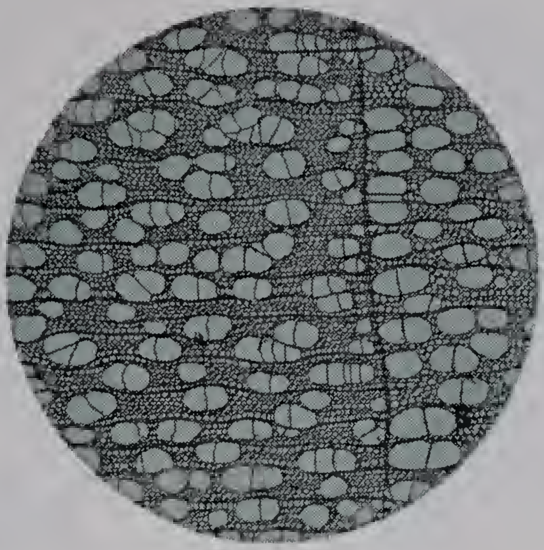
QUESTIONS FOR REVIEW

1. What prevents the bryophytes from growing into large plants?
2. Describe briefly the two phases in the life history of the moss.
3. What process separates the gametophyte from the sporophyte?
4. Describe briefly the formation of a peat bog.
5. In what ways are the mosses important to man?
6. Describe coal formation.
7. List the various structures in the order of their appearance in the life cycle of the fern.
8. Describe the way in which the fern produces its spores.
9. In what ways are the gametophyte generation and the sporophyte generation of the fern connected with each other?

APPLYING PRINCIPLES AND CONCEPTS

1. Why do you suppose that we seldom find more than one sporophyte growing from a single leafy stalk of moss, although that stalk usually bears more than one female sex organ?
2. What reasons can you give for the ferns dying out as the common plants in the world?
3. Compare the sporophyte plant of a moss and a fern, and explain in what ways the fern is more advanced.
4. List ways in which the fern is better suited to life on land than the moss.

CHAPTER 22



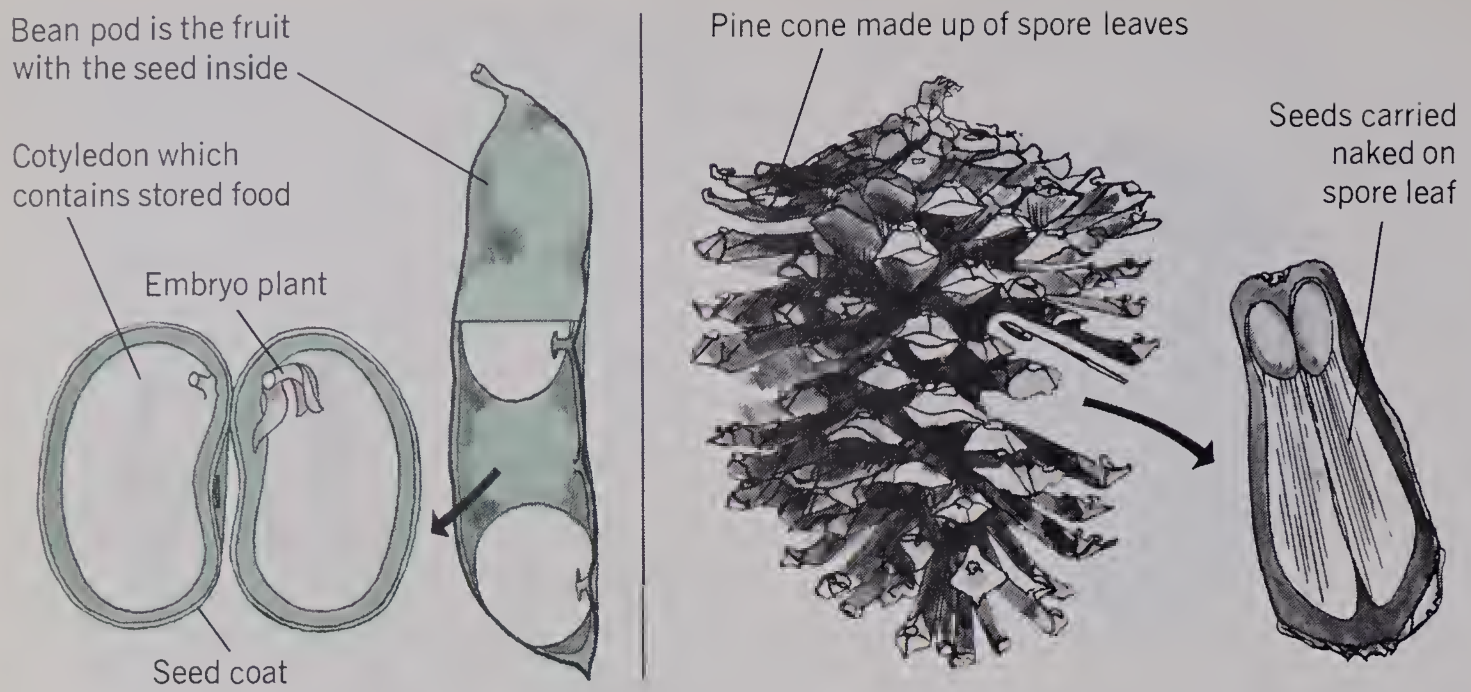
THE SEED PLANTS

What is a seed plant? The phylum Tracheophyta includes those plants having a vascular system with well-developed cells for the conduction of food and water. Included in this phylum with the ferns and fern allies are the great group of seed plants. Today these plants are the dominant forms found on land masses. Mosses and ferns, predominant in the past, are restricted in their environments to habitats where water is available at some season of the year, often in the shelter of large seed plants. Their sperm still require water to reach the eggs. Seed plants, on the other hand, are free of this total dependence on water for the completion of the reproductive process. Furthermore, the development of the seed, with its protection of the young sporophyte generation, has been of vital importance in the evolution of this great group of plants.

The seed plants are divided into two large classes: the ***Gymnospermae*** (plants whose seeds are not enclosed in a fruit, like the pine), and the ***Angiospermae*** (flowering plants like the apple). Thus, a pine tree and an apple tree are both seed plants, but they differ chiefly because the pine tree bears its seeds on the scales of its cones, while the apple tree bears its seeds enclosed in a fruit that came from a flower.

A ***seed*** is an embryo plant covered by one or more protective seed coats (Fig. 22–2). Food stored in a seed nourishes the young plant until it is established in its new location. In a sense, a seed is a packaged plant, ready for delivery. A seed may travel through the air, float in the water, be carried on the fur of an animal, or it may lie dormant for many months. When water and temperature conditions are favorable, the seed coats soften and the young plant pushes out its root and its shoot.

22-1 Cycads resemble both tree ferns and palm trees in appearance but their reproductive structures are like those of the gymnosperms. In early geological times they were abundant but are now more or less restricted to regions of warm climates. (U.S. Forest Service)


Bean pod is the fruit with the seed inside
Cotyledon which contains stored food
Embryo plant
Seed coat
Pine cone made up of spore leaves
Seeds carried naked on spore leaf

22-2 The main difference between the seed of an angioisperm like the bean and that of a gymnosperm like the pine is that the bean seed is enclosed in a fruit, while the pine seed is located on the scales of the pine cone and thus is not enclosed in a fruit.

By means of seeds, plants spread to new locations. Reproduction by seeds is highly efficient. It is one of the reasons why the seed plants have gained domination of the earth.

Characteristics of the gymnosperms. This class is older and more primitive than the angiosperms. The name means "naked seeds" and refers to the fact that the seeds are not enclosed in a fruit. Like the mosses and ferns, many gymnosperms were in their prime during the Carboniferous period. Most of these ancient genera are now extinct, so that we know about them only from their fossil remains. However, many of this class exist today and are familiar to you as the group of conifers that includes the pines, firs, cedars, spruces, yews, and others.

Many years ago priests of China found a curious tree in the forests of the interior and planted it in the temple gardens. Later it was introduced into gardens in Japan. Little did these ancient priests know that they had found and preserved the last species of an order of gymnosperms, the Ginkgoales (ging-koh-*ay*-leez). You may know the ginkgo tree (*Ginkgo biloba*), for it is now cultivated in the United States and other countries.

The deciduous leaves of the ginkgo are wedge-shaped and two-lobed, unlike those of any other tree. Most of the leaves grow in clusters at the tips of curious spurs spaced along the branches. Some of the branches lack these spurs. The ginkgo is often called the maidenhair tree because its leaves closely resemble those of the maidenhair fern. Its seed-bearing structures look like fruits, but they are structurally more like cones.

The ginkgo is a fine tree for planting in the yard. Although slow growing, it will eventually reach a height of 100 feet with a diameter of nearly four feet. If you do plant a ginkgo, you will have one of the rarest of all living plants — a single species of a single genus — the last survivor of an entire order.

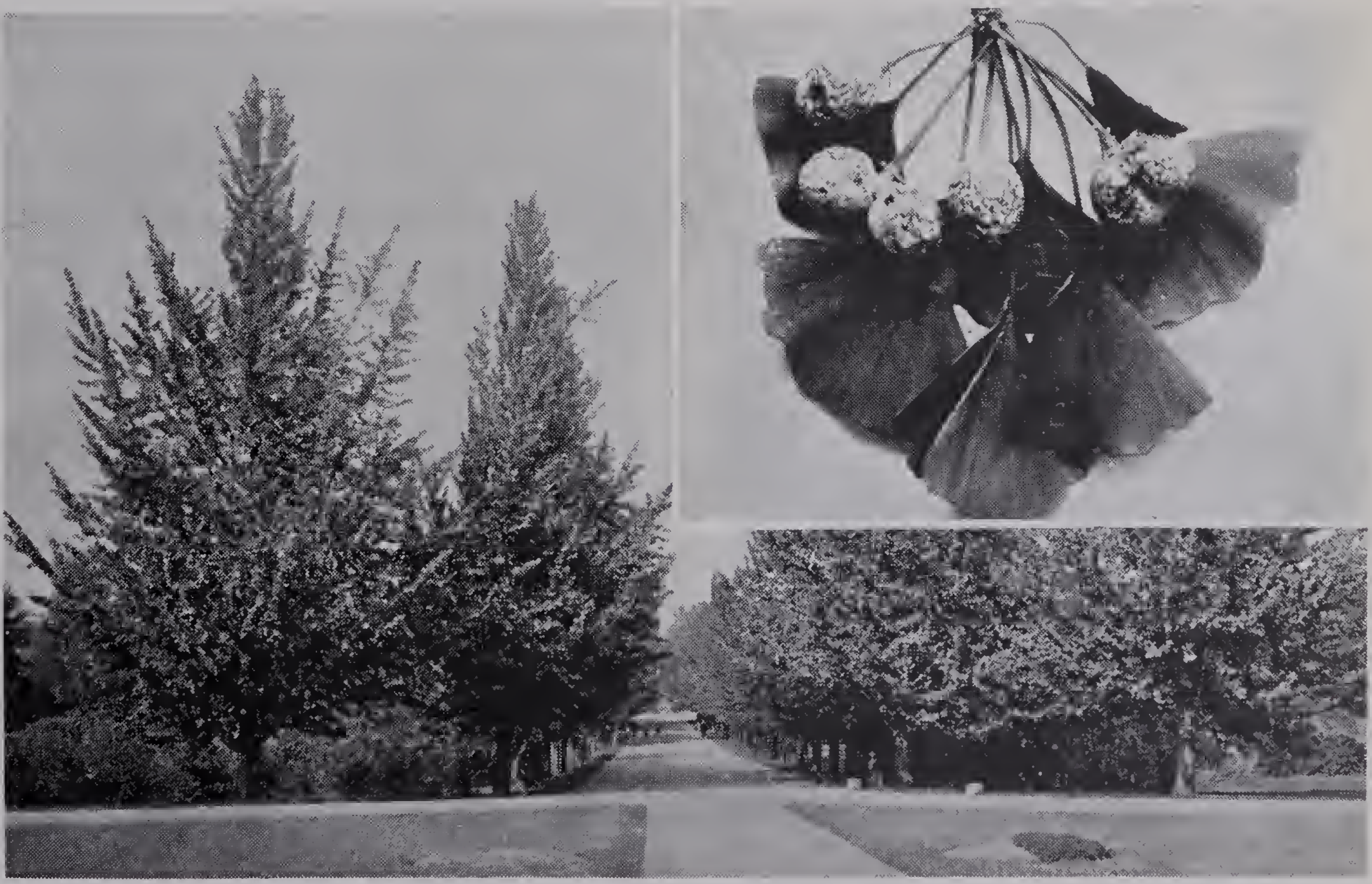
Cone-bearing gymnosperms – the conifers. The name ***conifer*** refers to the fact that trees of this class of gymnosperms bear woody ***cones*** composed of scales. These scales bear winged seeds on their upper surface.

Conifer leaves are either in the form of needles or scales. Most coniferous trees keep some of their needles all winter. The new ones that are formed in the spring take the place of the old ones that fall to the ground. Exceptions to this are the bald cypress and the larch. These two conifers lose all their needles each autumn.

Of all the gymnosperms that ever existed, the conifers are the best suited to present world environments. Many coniferous species have disappeared, but others still flourish and are dominant in many parts of North America. The table on page 306 lists the genera of modern North American conifers. We have included the scientific names of these genera because you will see them if you look at nursery catalogs. Small conifers are widely used around houses. Large conifers such as pines, spruces, and hemlocks are widely planted as windbreaks around farmhouses and as trees in city yards. The Colorado blue spruce is unsurpassed as a single tree in a yard planting.

Conifers are most important as timber trees. Many species thrive in sandy and rocky soils, which are unsuitable for the broad-leaved forest trees.

Before leaving the conifers, we might mention that they hold the record for height, trunk diameter, and age among trees. A giant redwood, in the Calaveras Grove in California towers 300 feet above the ground. This tree is over 30 feet in diameter and is esti-



22-3 The ginkgo tree was once found only in China and Japan, but is now a familiar sight in the United States. The insert shows the seed-bearing structures. (U.S. Forest Service)

CONIFERS TODAY

Pine (*Pinus*)
Spruce (*Picea*)
Fir (*Abies*)
Hemlock (*Tsuga*)
Red cedar (*Juniperus*)
White cedar, arborvitae (*Thuja*)
Bald cypress (*Taxodium*)
Redwood (*Sequoia*)
Douglas fir (*Pseudotsuga*)
Yew (*Taxus*)
Larch, tamarack (*Larix*)

mated to be 4,000 years old. Even this trunk diameter and age are surpassed by a cypress tree, the Big Tree of Tule, growing about 200 miles south of Mexico City. It is 50 feet in diameter and is estimated to be over 5,000 years old.

Characteristics of the angiosperms. The class Angiospermae includes the great majority of green plants existing today. The flowering plants probably evolved from gymnosperm ancestors during the Mesozoic era. Even some modern gymnosperms show characteristics transitional between the two.

22-4 Conifers have their leaves in the form either of needles or small scales. They are among our most valuable timber trees. Here you see a stand of young loblolly pine trees. (International Paper Company)

All angiosperms have flowers of some sort; all bear seeds enclosed in an ovary wall; and the seeds contain an embryo that possesses either one or two cotyledons. A ***cotyledon*** (kaht-il-*ee*-don) is the first leaf of the embryo plant; it may act as a food reservoir until the new plant develops green tissue and can synthesize its own food. On the other hand, it may serve as the first photosynthetic organ of the seedling.

The angiosperms are divided into two subclasses, depending on the number of cotyledons, as follows: the ***Monocotyledonae*** (*mahn*-o-kaht-l-*ee*-duh-nee) and the ***Dicotyledonae*** (*dy*-kaht-l-*ee*-duh-nee). As the names imply, a monocot embryo bears one while that of a dicot has two cotyledons. As we study the flowering plants, we shall point out other differences between monocots and dicots, such as in the arrangement of root and stem tissues, the organization of leaf veins, and the number of flower parts. Some families of monocots and dicots are listed on pages 308 and 309.

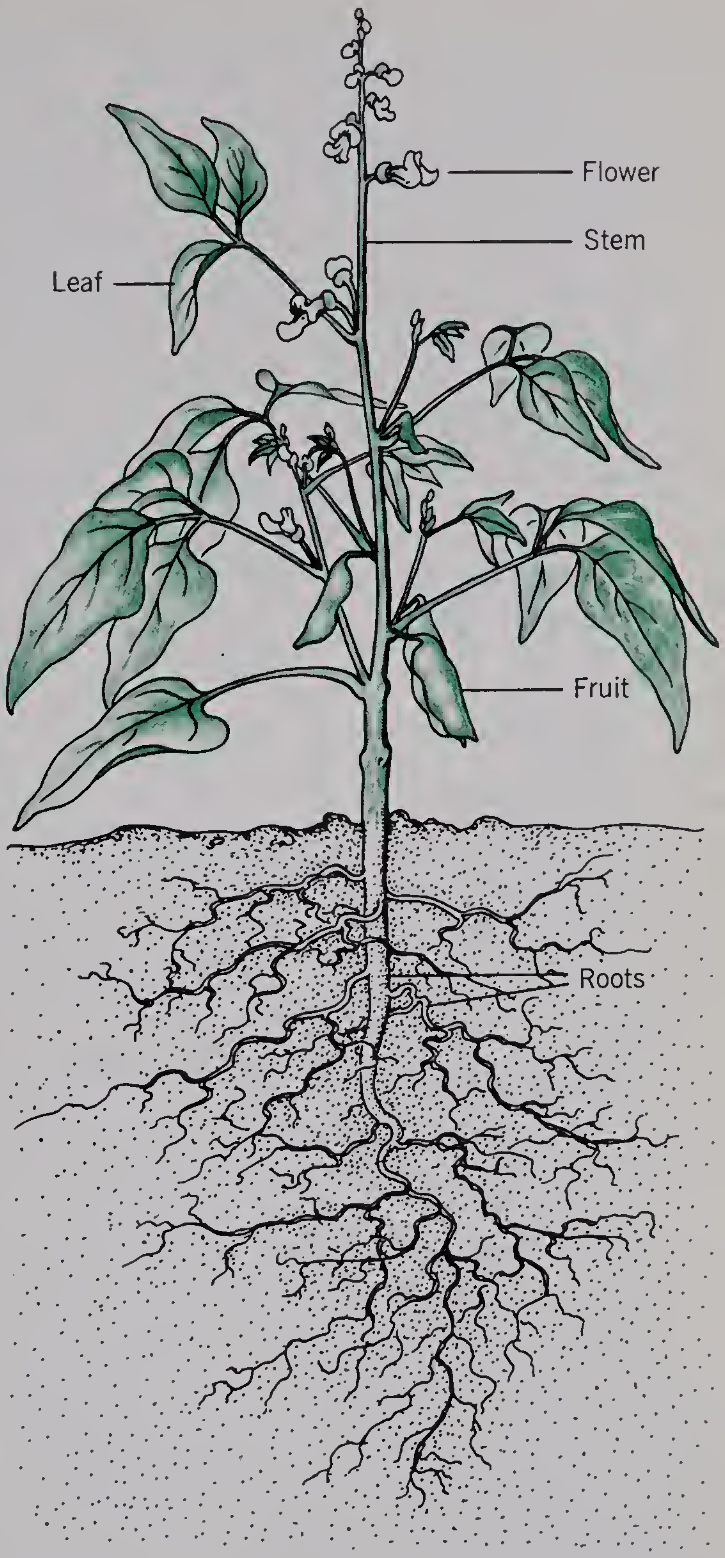
The plant body of a flowering plant. Each organ of a flowering plant is highly developed for performing certain activities (Fig. 22–5). The root, stem, and leaf are ***vegetative organs.*** They perform all the processes necessary for life *except* the formation of seeds. This does not mean, however, that plants cannot multiply directly from their roots, stems, or leaves. If you have sprouted roots on a pussy willow stem in a jar of water, you know you can plant the stem and grow a new plant. Root, stem, and leaf cuttings, as well as budding and grafting, are methods of vegetative reproduction.

The ***root** anchors* the plant in the ground. It spreads through the soil and *absorbs* water and soil minerals. It *conducts* these to the stem for delivery to the leaves. Many roots *store* food and return to the plant as needed.

The ***stem*** produces the leaves and *displays* them to the light. It is a busy thoroughfare, for it *conducts* water and minerals upward and carries foods that have been manufactured in the leaves downward. Like the root the stem often serves as a place of food *storage*. In many plants green stems aid the leaves in photosynthesis.

The ***leaf*** is the center of much of the plant's activity. It is the chief center of photosynthesis. It also exchanges gases with the atmosphere in the process of *respiration*. Much of the water absorbed by the root has a one-way trip through the plant. It escapes from the leaf as water vapor in the process called *transpiration* about which you will learn in Chapter 25.

After a period of growth a plant usually starts reproduction. ***Flowers*** are specialized organs for sexual reproduction. They are followed by ***fruits*** with their ***seeds***. As the flower withers, the fruit develops from certain of its parts. Within the fruit are the seeds, each containing an embryo plant, which are ready to be carried to a new location. There they sprout and establish a new generation of the same kind of plant.



22-5 This drawing of a bean plant has the chief organs labeled. What is the function of each?

Tissues of flowering plants. The various organs of higher plants perform their activities with great effectiveness because of the specialized tissues that form them. We shall study these tissues more thoroughly when we discuss each of the plant organs in greater detail in the chapters to follow. However, before dealing with any individual organ, you should be familiar with the names of various tissues and the general functions of each.

SOME FAMILIES OF MONOCOTS

Family	*Familiar Members*
Cattail (Typhaceae)	Common cattail
Grass (Gramineae)	Cereal grains, bluegrass, sugar cane, bamboo, timothy
Sedge (Cyperaceae)	Sedges
Arum (Araceae)	Indian turnip (Jack-in-the-pulpit), skunk cabbage, calla lily
Pineapple (Bromeliaceae)	Pineapple, Spanish moss
Lily (Liliaceae)	Lily, onion, tulip, hyacinth
Amaryllis (Amaryllidaceae)	Amaryllis
Iris (Iridaceae)	Flag, iris
Orchis (Orchidaceae)	Lady's slipper, orchis, orchid
Palm (Palmaceae)	Coconut palm, date palm, palmetto

The tissues of flowering plants are summarized as follows:

Epidermis — an outer layer which reduces loss of water, and protects against injury and the entry of disease-causing organisms.

Cork — a waterproof covering of nonliving cells, especially in woody plants. It serves the same general purpose as an epidermis but is even more effective.

Parenchyma (pa-*ren*-kih-mah) — a thin-walled, soft tissue of the type forming flower petals, leaf blades, and the *cortex* and *pith* regions of stems and roots. Food manufacture and storage of food and water are functions of parenchyma tissues.

Xylem (*zy*-lem) — a supporting and conducting tissue. Large multicellular structures called *vessels* and small cells called *tracheids* are thick-walled conducting tubes. Xylem *fibers* give strength, especially to stems and roots.

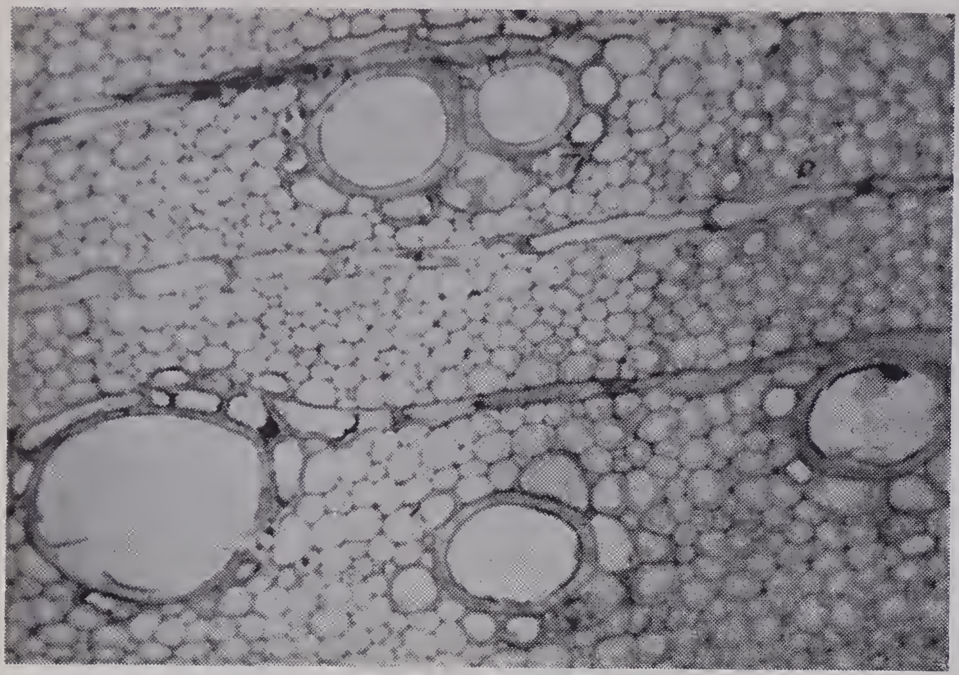
Phloem (*floh*-em) — a tissue including long, multicellular structures called *sieve tubes*, for conduction and phloem *fibers* for support. Phloem comprises what is called the inner bark of trees.

Meristematic tissue — composed of small, actively dividing cells. During the growing season the cells in meristematic tissues divide often and give rise to cells that mature into other plant tissues. Meristematic tissue at the tips of roots and in the buds of stems forms the tissues that result in growth in length. The *cambium* layer between the bark and the wood causes growth in diameter.

Herbaceous and woody plants. Any plant with a stem that is not woody and that dies to the ground at the end of the

SOME FAMILIES OF DICOTS

Family	*Familiar Members*
Willow (Salicaceae)	Willow, poplar (cottonwood), aspen
Walnut (Juglandaceae)	Walnut, hickory
Birch (Betulaceae)	Birch, alder, hazel
Beech (Fagaceae)	Beech, chestnut, oak
Pink (Caryophyllaceae)	Pink, carnation, chickweed
Water lily (Nymphaeaceae)	Water lily, pond lily
Crowfoot (Ranunculaceae)	Buttercup, hepatica, columbine, delphinium, larkspur
Poppy (Papaveraceae)	Poppy, bloodroot
Mustard (Cruciferae)	Mustard, radish, turnip, cress
Rose (Rosaceae)	Rose, apple, hawthorn, strawberry, pear, peach, plum, cherry
Pulse (legume) (Leguminosae)	Bean, pea, clover, alfalfa, locust, redbud
Flax (Linaceae)	Flax
Maple (Aceraceae)	Maple
Mallow (Malvaceae)	Marshmallow, hollyhock, hibiscus
Parsley (Umbelliferae)	Parsley, parsnip, carrot, sweet cicely
Heath (Ericaceae)	Laurel, rhododendron, azalea, heather, blueberry, cranberry, huckleberry
Mint (Labiatae)	Catnip, spearmint, peppermint, sage
Nightshade (Solanaceae)	Tomato, potato, tobacco
Figwort (Scrophulariaceae)	Mullein, snapdragon, digitalis (foxglove)
Composite (Compositae)	Dandelion, daisy, sunflower, zinnia, aster, marigold, thistle, dahlia

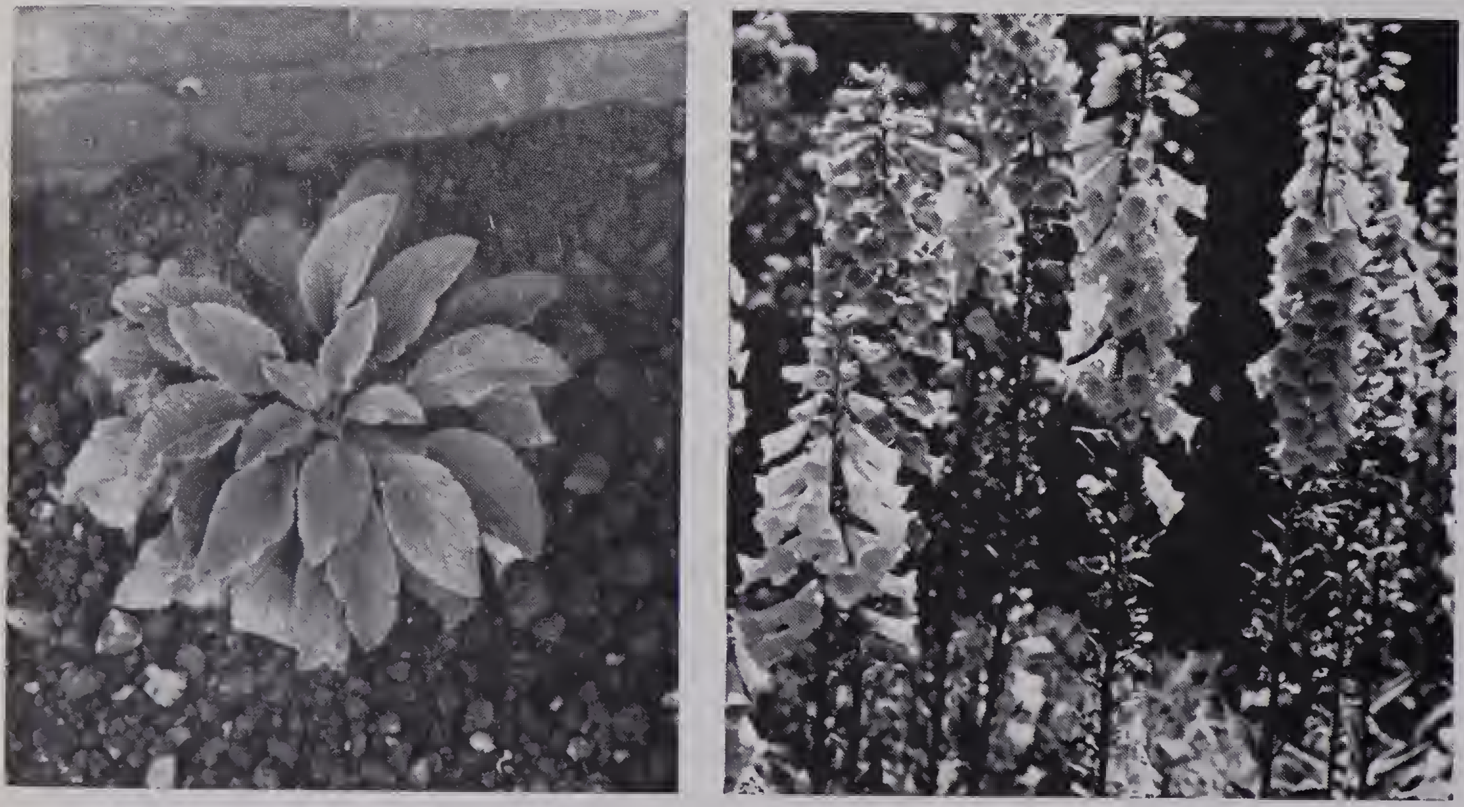


22-6 This is a highly magnified photograph of xylem tissue found in the ash tree. The large openings are the vessels while the smaller ones are tracheids. (International Paper Co.)

growing season is called ***herbaceous*** (her-*bay*-shus) by the biologist. Garden vegetables and flowers, cereal grains, and many of our common weeds are herbaceous.

Woody plants include trees, shrubs, and certain vines such as the wild grape, Virginia creeper, and poison ivy. In a woody stem growth in diameter is assured by the cambium tissue that produces new cells year after year. Growth in length of the stem continues each year from meristematic tissues in various growing points.

Various life spans of the seed plants. Plants that live for only one season are called ***annuals.*** These plants, such as the zinnia, marigold, bean, and pea,



22-7 The rosette of basal leaves on the left is the first year's growth of foxglove, which is a biennial. The second year's growth of this plant produces an attractive spike of flowers which mature into fruit containing the seeds. Then the plant dies. (Left: Albert Towle; right: Walter Dawn) grow from a seed, mature, reproduce, and die in a single growing season.

Biennials live two seasons. The first year they produce roots, stems, and leaves only. The plant then grows during its second season and bears the flowers; when seeds are produced, the plant dies. Beets, carrots, and parsnips are biennial vegetables. Among the biennial garden flowers are the sweet William, digitalis (foxglove), and Canterbury bells.

Perennials live more than two seasons. Most perennials form roots, stems, and leaves the first year, but do not produce flowers until a season or more later. Herbaceous perennials die to the ground each year. The roots and any underground stems remain alive and give rise to new aerial stems and leaves each season. Delphiniums, lilies, columbines, and irises are herbaceous perennials. Woody perennials include the trees, shrubs, and many vines. Once perennials have started to flower, they usually continue season after season, if environmental conditions remain favorable.

IN CONCLUSION

The seed plants are the dominant form of plant life in the world today, having replaced the mosses and ferns of an earlier era. The most familiar members of the class Gymnospermae are the conifers. The class Angiospermae includes all the true flowering plants. The vegetative organs of a flowering plant include the root, the stem, and the leaf. The flower is the reproductive organ from which fruits and seeds develop. In addition to these organs, flowering plants have several highly specialized tissues and definite growing seasons.

What if the seed plants had not replaced most of the more primitive ferns and mosses during the past ages? There would have been no cereal grains for flour, no potatoes, tomatoes, lettuce, onions, radishes, and other vegetables in our stores. Could our civilization ever have developed in such plant surroundings? You might debate this point, but one thing is certain. Our plant and animal industries, in fact, our very survival, is geared to the seed plants.

In the next chapter we shall start with the first root that grows from a seed. In other chapters we shall study the vegetative organs and then the reproductive organs of flowering plants. We shall return to the seed again as the climax of reproduction.

BIOLOGICALLY SPEAKING

Angiospermae
annual
biennial
cones
conifer
cork
cotyledon
Dicotyledonae
epidermis
flower
fruit
Gymnospermae
herbaceous
leaf
meristematic tissue
Monocotyledonae
parenchyma
perennial
phloem
root
seed
stem
vegetative organs
woody
xylem

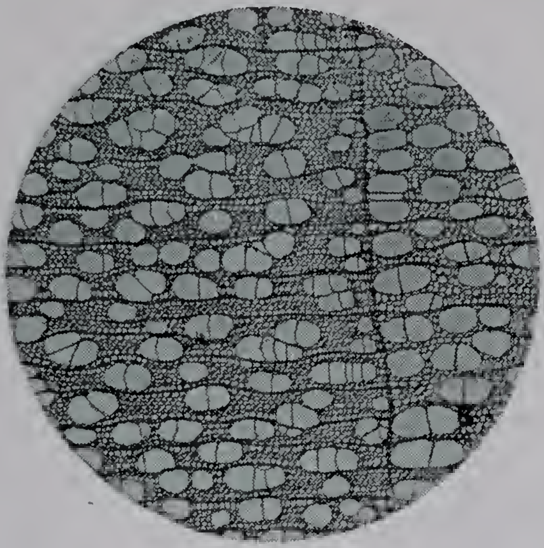
QUESTIONS FOR REVIEW

1. On what basis are the seed plants divided into two great classes — gymnosperms and angiosperms?
2. Explain why we speak of the ginkgo tree as a "living fossil."
3. Describe several uses made of conifers in yard plantings.
4. Name five well known families of monocots and five well known dicot families.
5. Name the three vegetative organs of a seed plant, and describe briefly the functions of each organ.
6. List five specialized tissues of a seed plant.
7. Distinguish between herbaceous and woody plants. Give several examples of each type.
8. Discuss the life cycle of annual, biennial, and perennial seed plants.

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss possible reasons for the disappearance of most gymnosperms and the rise of angiosperms through past ages.
2. Discuss various ways in which high development of the organs of angiosperm plants has given them an advantage over other kinds of plants in the struggle for existence.
3. Many of our most beautiful garden flowers are annuals. Why are they ideally suited to garden needs?

CHAPTER 23



ROOT STRUCTURE AND FUNCTION

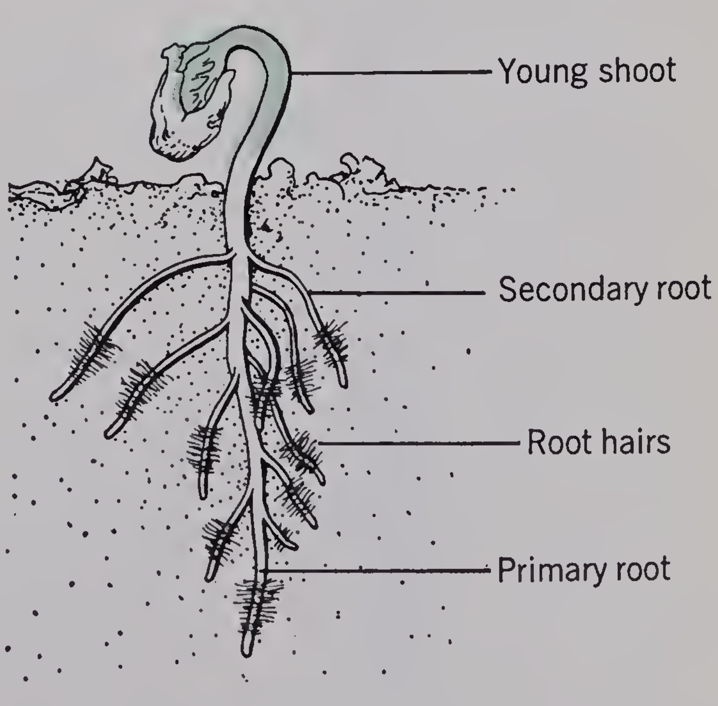
The origin of root systems. When a seed first begins to grow, the ***primary root*** pushes out through the seed coat, lengthens rapidly, and quickly pushes its way down into the soil. After a short period of growth ***secondary roots*** begin to appear. These tiny branches come out first near the tip of the primary root and farther down as the root grows. From them arise still more secondary roots, so that branching and rebranching may develop a complicated root system.

You have probably wondered how a root system compares in size with the stem and branches. There is no definite rule, as the roots of different plants vary widely, and the size of a root system differs in various soil conditions. But you can estimate that the average land plant has about as much or more below ground as above ground.

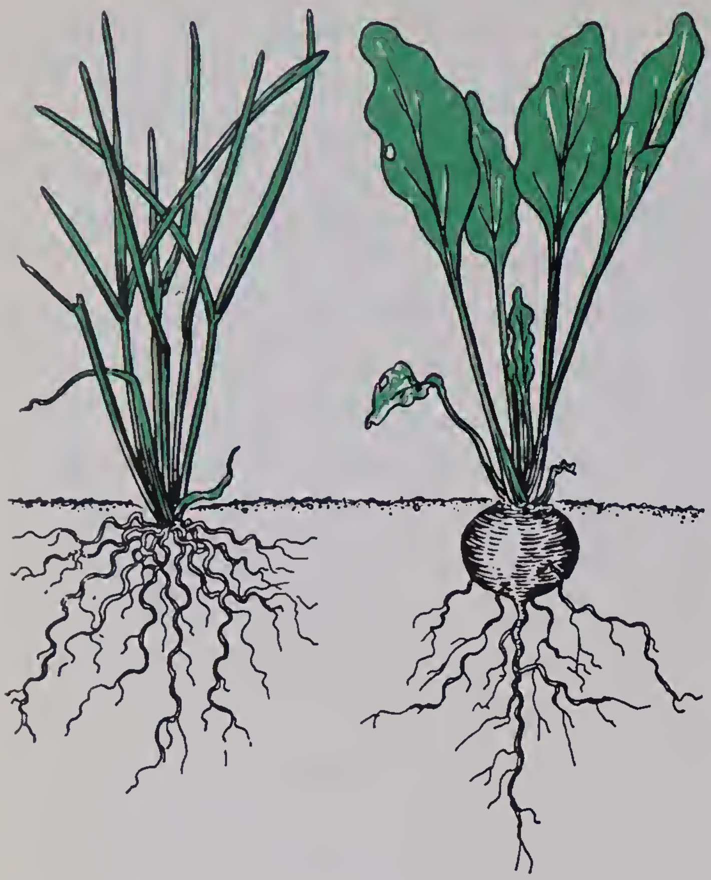
Types of root systems. If a primary root continues to grow, it will always be the largest member of the root system. As such it is known as a ***taproot.*** Taproots may be round as in the beet, turnip, and radish, or long and slender as in the carrot and parsnip. The taproot of alfalfa grows to 15 feet or more.

Taproots are an ideal anchorage of the plant. Furthermore, they can often withstand prolonged drought because they can get at the deep water supply. This accounts for the fact that alfalfa absorbs water after the grasses growing with it may have turned yellow and brown. It also explains why some plants thrive on dry hillsides and why others survive in arid regions. Taproots also serve as underground storehouses for the food supply of the plant. For this reason many of these roots are used as food by man.

In many plants the primary root lives only a short time and is quickly replaced by a whole mass of slender secondary roots that branch and rebranch in all directions. These are called ***fibrous roots.*** Grasses, corn, wheat, and many trees and shrubs have fibrous root systems. Such systems are of great advantage in absorbing water and minerals



23-1 Secondary roots branch out from the primary root and grow until the complete root system has formed.



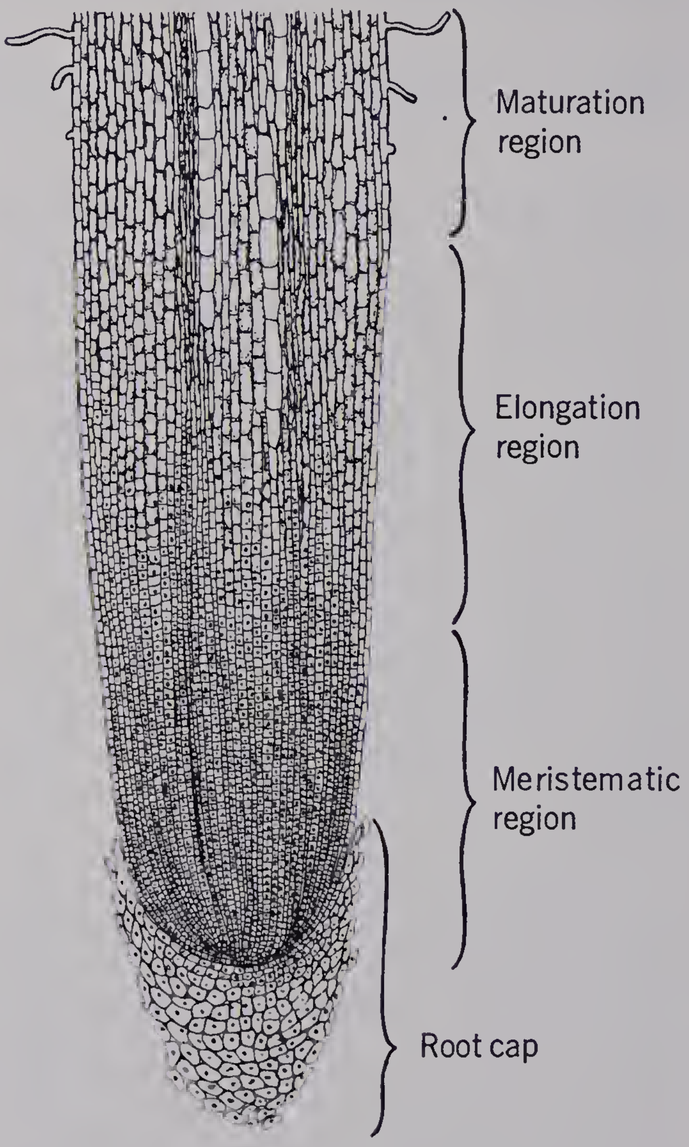
23-2 Compare the fibrous root system of the plant on the left with the taproot system of the plant on the right. Which acts as the better soil binder?

after a rain. During dry periods fibrous roots cling to soil particles, preventing the soil from being carried away by the wind. For this reason, man uses plants with fibrous roots to hold the soil in sandy areas and on steep slopes.

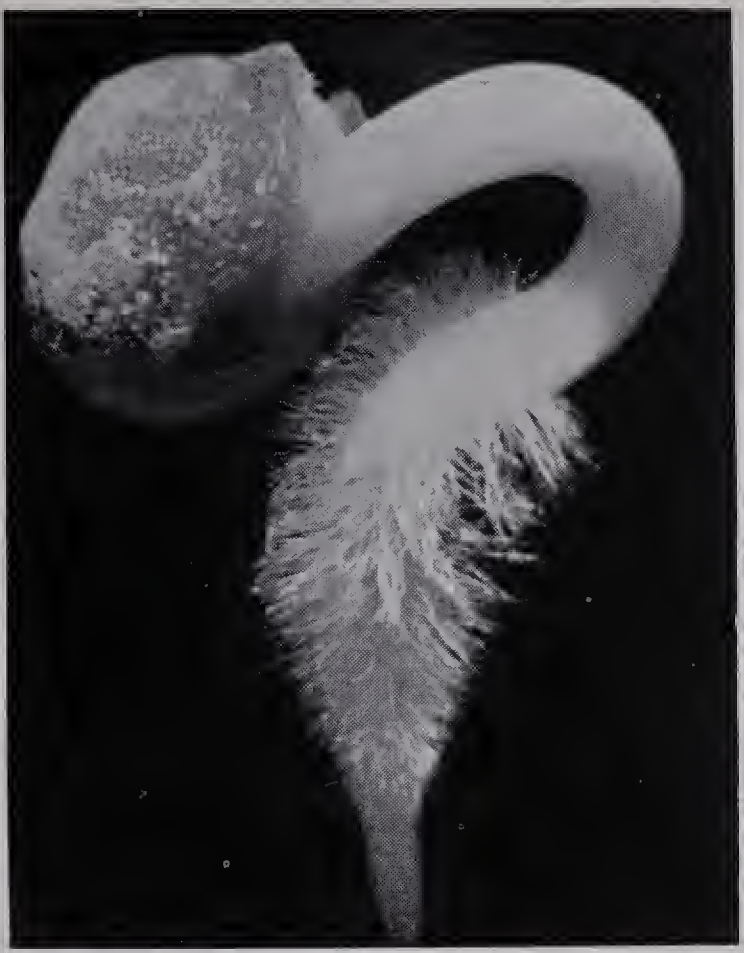
The regions of a root tip. If you cut off a young root half an inch or so back of the tip, slice it thinly lengthwise, and examine it with a microscope, you will see the cells composing it and also several important regions. The region at the tip, the ***root cap***, protects the delicate end. As the cap is pushed through the soil by the growing root behind it, its outer surface is torn away. The addition of new cells to the inner surface, however, keeps it in constant repair.

You may wonder at the fact that the delicate root tip can force its way through soil without damage. The root tip partly pushes its way through soil. Root caps give off carbon dioxide, which combines with soil water to form a weak acid called carbonic acid. This carbonic acid aids the progress of the young root by dissolving certain minerals in its path. When roots grow over limestone rocks, their pattern is often etched into the rock surface by the carbonic acid they form.

Immediately behind the cap, at the tip of the root proper, is the ***meristematic region***, or growing point of the root. Cells of this region are small and are constantly dividing by mitosis, thus giving rise to new root cells.



23-3 This drawing represents a root tip as you see it under the microscope. Notice the blunt, thimble-shaped root cap which protects the delicate meristematic region from injury by soil particles.



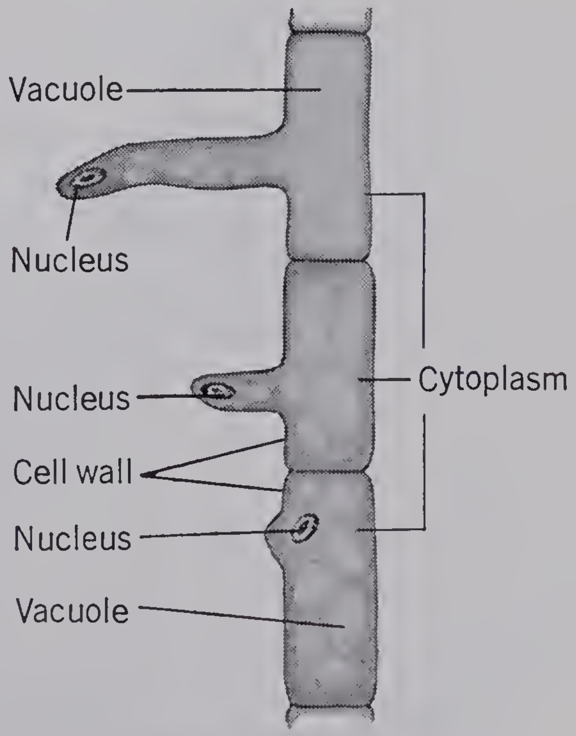
23-4 This photograph of a radish seedling gives you an idea of the number of root hairs a very young root has. (Hugh Spencer)

Back of the meristematic region cells gradually lengthen until they reach full length a considerable distance from the tip of the root. This lengthening of cells marks the ***elongation region,*** which causes the forward movement in the growth of the root tip.

After the cells have grown to full length, they change further. Cells on the surface give rise to tiny projections called ***root hairs.*** Root hairs may be seen as a white, fuzzy growth a short distance back of the tip of a young root. They should not be confused with secondary roots, which, like primary roots, are composed of many cells. Root hairs are produced in a zone one to two inches long. As the tip of the root moves downward, new root hairs form close to the tip and older ones wither away. Thus they are constantly extending into new areas of soil as the young root pushes on. Root hairs are an ideal adaptation for absorption. Because of their small size, they come into intimate contact with soil particles. Since they are extensions of single cells and are covered only with a plasma membrane and cell wall, water passes into them freely. Most importantly, they increase the absorptive surface of the root.

While cells on the surface of the young root give rise to root hairs, those inside the root change somewhat as they become special tissues of the mature root. Modification of cells to form these special tissues marks the ***maturation region*** of the root.

Regions and tissues of a mature root. Microscopic examination of a prepared slide of a mature root shows its distinct tissues. The ***epidermis*** appears as a single layer of cells. Under the epidermis are layers of rounded, loosely packed parenchyma cells forming the ***cortex.*** This is the principal food storage area of the root, and is several cells thick. The ***endodermis*** is a single layer of cells, often with thick walls, located at the inside edge of the cortex.



23-5 Note that each root hair is an extension of one epidermal cell near the tip of a root.

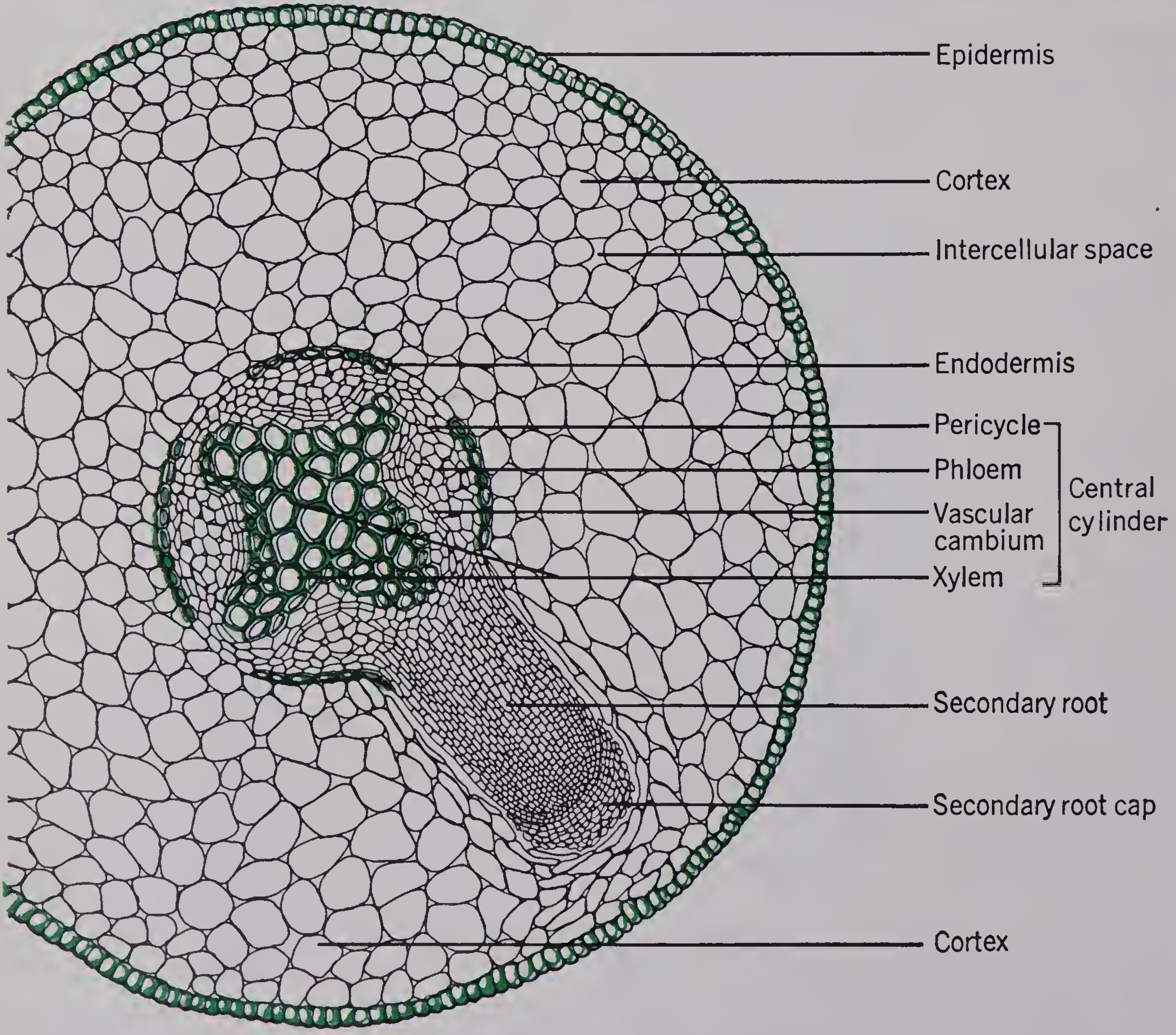
The *central cylinder* is the principal conducting and strengthening region of the root. It is composed of xylem and phloem tissues, and may contain vascular cambium and pith tissues.

The *pericycle* is a layer of very thin-walled cells lying at the outer edge of the central cylinder and just inside the endodermis.

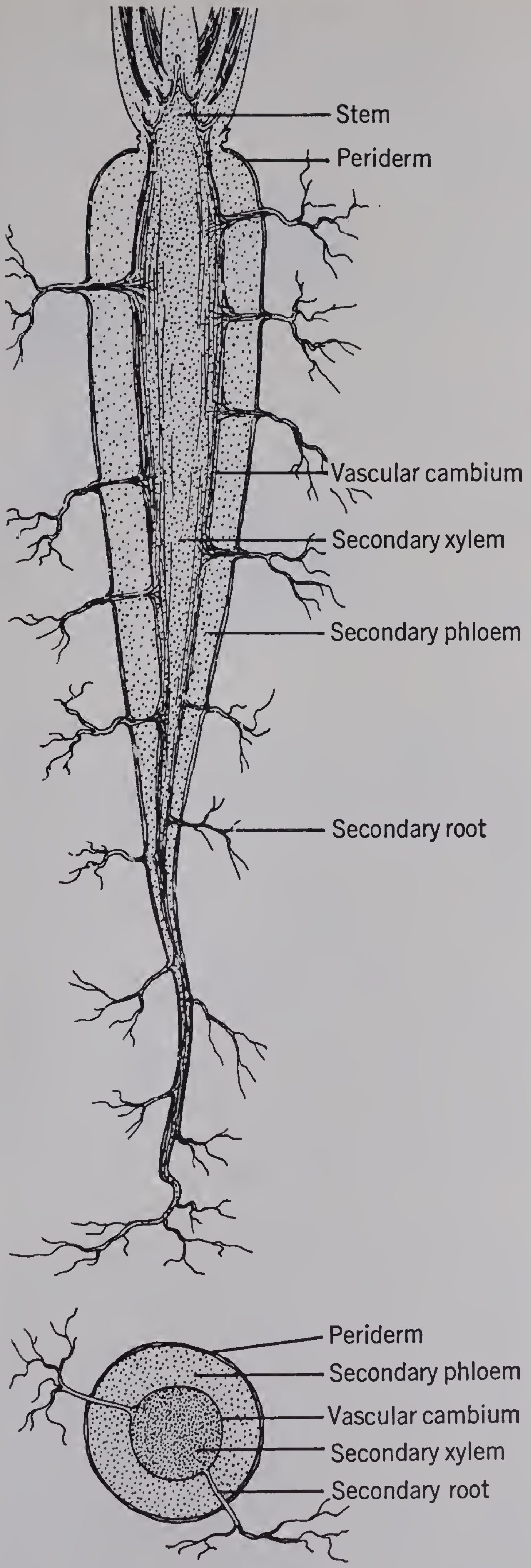
The *xylem* is the water-conducting tissue. Through the xylem water and soil minerals travel upward to the stem and leaves. The conducting portion of the xylem is composed of various types of large, thick-walled cells. They are long, empty cells that resemble pipes. These cells live only a short time but continue to serve as channels of conduction long after death. In addition, the xylem contains numerous smaller cells that give great strength to the root. We commonly speak of the xylem tissues of a mature plant as *wood*.

The ***phloem***, or food-conducting tissue, lies outside the xylem. If the xylem is arranged in the form of a cross as in some roots, like the buttercup shown in Fig. 23–6, you can find the phloem between the arms of the cross in rounded groups. Foods, produced in the stem and leaves, travel downward through the phloem cells.

Secondary thickening in the root. The primary tissues we have described do not


Epidermis
Cortex
Intercellular space
Endodermis
Pericycle
Phloem
Vascular cambium
Xylem
Central cylinder
Secondary root
Secondary root cap
Cortex

23-6 This drawing of a young buttercup root shows the various tissues and also the origin of a secondary root.



23-7 As you study the tissues in the longitudinal section through the carrot root, compare the location of the same tissues in the cross section.

increase as the root continues its growth in diameter. However, the ***vascular cambium*** adds secondary xylem on its inner side and secondary phloem on its outer side by continuous cell division during the growing season. This produces a root of which the carrot is an example.

The outer edge is a tough layer, the periderm, which develops from the pericycle. Inside this layer is a thick one of phloem, most of which has been formed by the vascular cambium. The vascular cambium appears as a layer of cells at the inner edge of the phloem. The center of the carrot is xylem, much of which was formed by the vascular cambium during secondary thickening. Notice that the secondary roots extend from the xylem, thus joining the conducting vessels of the secondary roots with those of the primary root. The root tissues and their functions are summarized in the table on page 318.

An old root, such as the root of a tree, contains many layers of xylem and phloem, formed by the vascular cambium each season. The outside of the root is covered with a thick layer of bark. Such a root is an efficient organ of conduction and anchorage, but the thickened portion no longer absorbs water.

Various root adaptations. Although all roots have, in general, the tissues we have described above, in different species the root structure and behavior differs in ways that adapt different species to different habitats. Such plants as the duckweed and the water hyacinth have ***aquatic roots*** which usually lack root hairs. They do not need extra surface on the epidermis for absorption because they live in a water environment.

The bald cypresses of the southern United States grow in swamps and are

SUMMARY OF ROOT TISSUES AND THEIR SPECIAL FUNCTIONS

Tissue	*Function*
Epidermis	Absorption and protection
Root hairs	Increase of absorption area
Cortex	Storage of food and water
Endodermis (boundary layer)	Separation of cortex from central cylinder, and conduction
Central cylinder	
Pericycle	Origin of secondary roots and formation of periderm
Xylem	Conduction of water and dissolved minerals upward to the stem and leaves
Phloem	Conduction of manufactured food downward from the stem and leaves
Vascular cambium	Production of secondary xylem and phloem

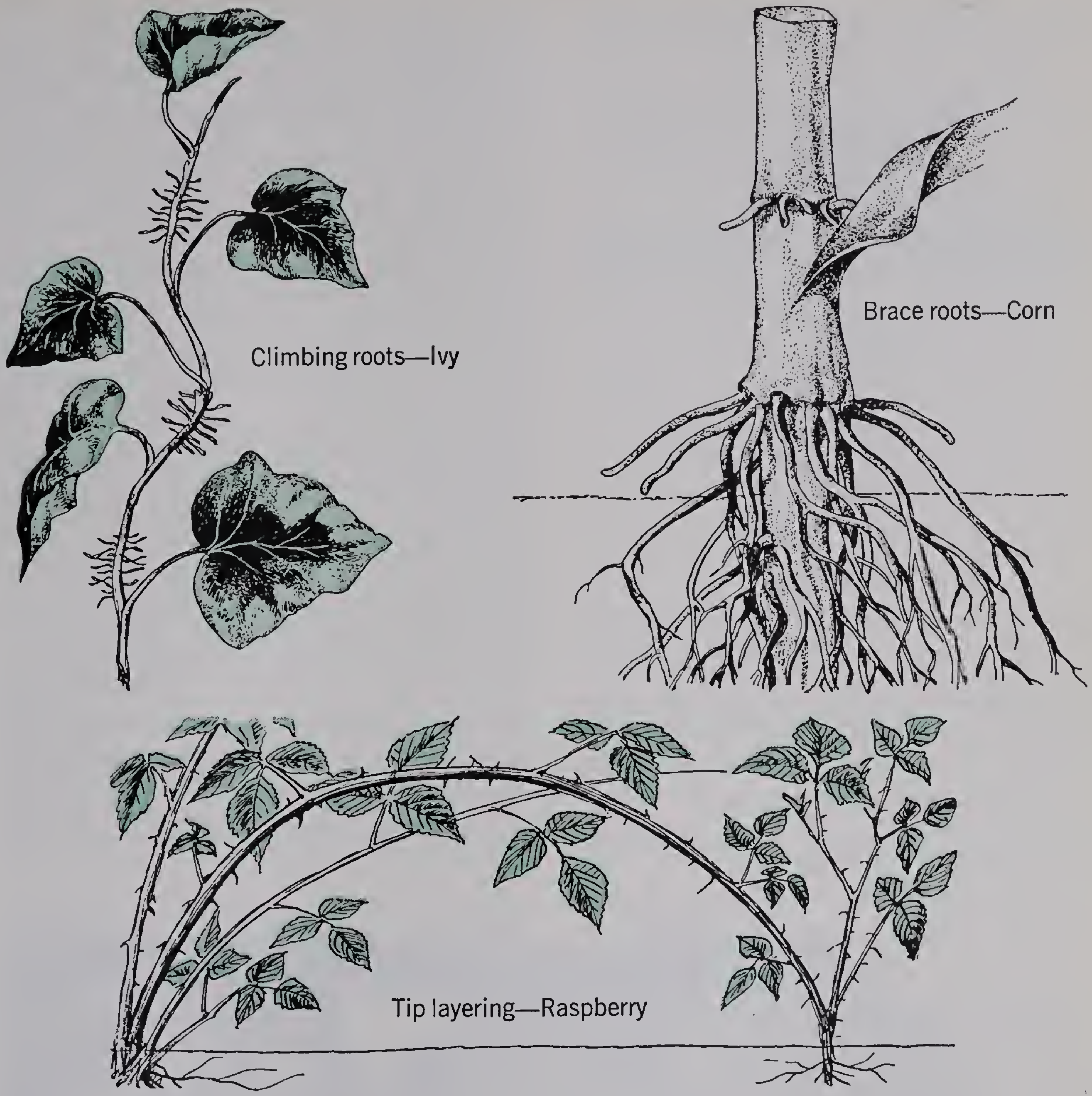
rooted in water-covered soil. To supply the submerged roots with air, the roots send structures called *knees* above the water. Cypress knees contain air-conducting tissues that are connected with the roots (Fig. 23–8).

Many plants in the tropics produce ***aerial roots.*** Tropical orchids live on trees and absorb water from the humid atmosphere. The various debris that collects around the roots is enough to supply the mineral needs. Aerial roots have a thick, spongy cortex, making possible rapid absorption of the rainwater and dew that falls on them.

23-8 What is the function of the bald cypress knees shown? (Walter Dawn)

The roots we have discussed thus far have developed from the primary root or from one of its branches. However, in some plants ***adventitious*** (ad-ven-*tish*-us) roots develop from the stem or even from the leaves.

You have probably noticed the circle of roots that grows from the joint of the corn plant just above the ground (Fig. 23–9). These are a kind of adventitious root called *prop roots,* or *brace roots.* They grow into the ground and help the underground roots support the stem. If soil is piled around the stem, additional brace roots develop from the next joint above the soil line. In fact, all the roots of the corn plant are really adventitious, since they come from the stem rather than from the short-lived primary root.



23-9 The various types of roots shown here are adventitious; that is, they develop from stems.

Poison ivy, English ivy, and other vines produce clusters of roots along the stem. These roots cling to a wall or to some other support and hold the stem securely. Such plants also have ordinary soil roots that absorb water and dissolved minerals.

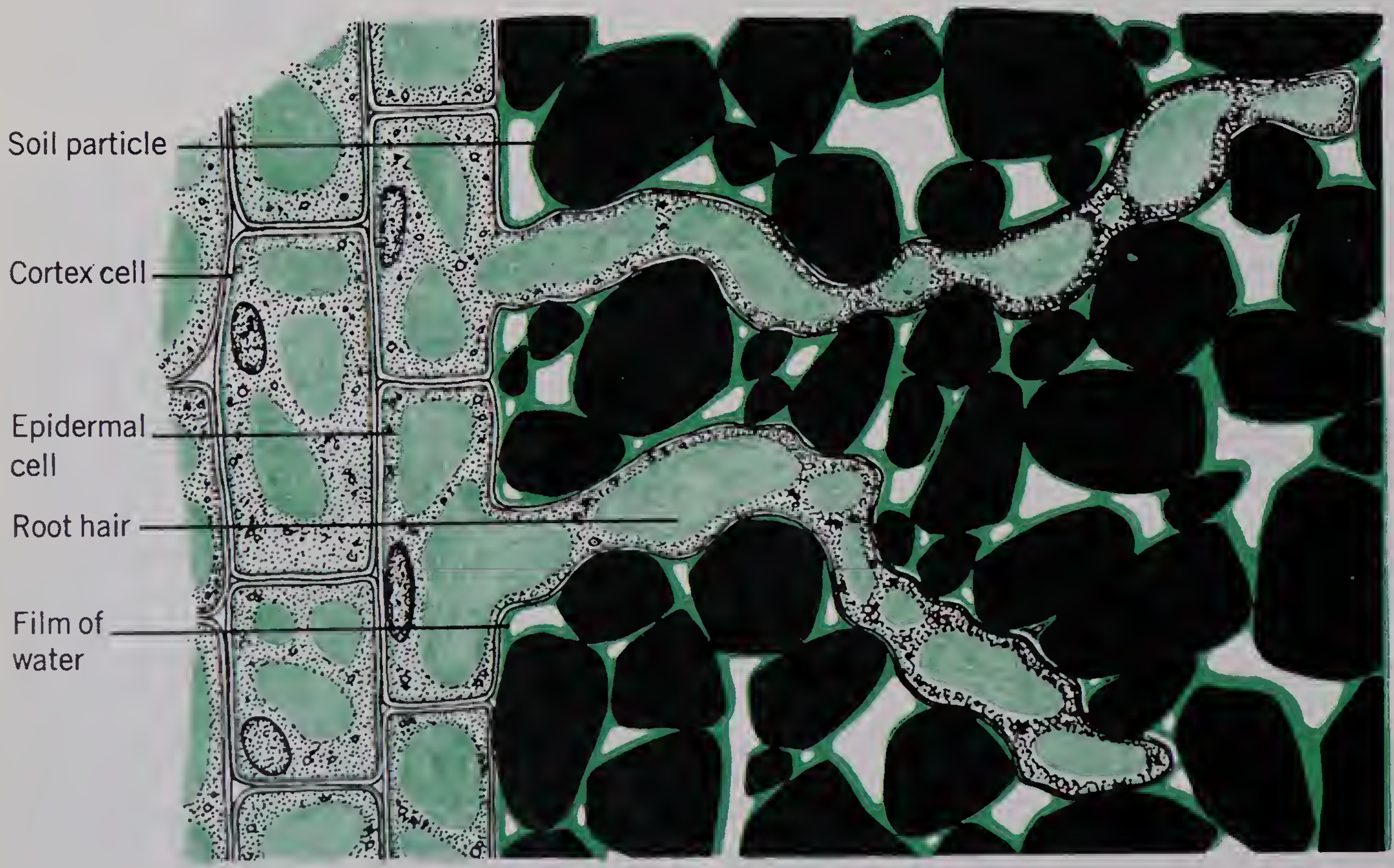
Vegetative reproduction by roots. We do not ordinarily think of roots as being organs of reproduction, but they may act as such in certain plants. Some perennial garden plants produce large numbers of secondary roots each year. When these are removed from the parent plant, they produce stems, leaves, flowers, and fruit. Many garden perennials such as peonies, phlox, and shasta daisies are produced commercially in this way.

In certain plants, if the stem lies in contact with the soil long enough, roots will grow from the joints and produce new plants. Climbing roses can be started by burying a portion of a stem until it has taken root. Raspberry bushes root from the stem in a similar way, except that the roots usually form at the tip of the stem (Fig. 23–9).

Other examples of adventitious roots for propagation include those that form on pussy willow stems when cut and put in a container of water, and the roots that form on strawberry runners as they grow into new areas.

The root as an organ of absorption. Although roots may anchor the plant and even reproduce it, the principal function of the root is absorption of water. To understand how the root accomplishes absorption, first review the osmosis experiment with the thistle tube that was described in Chapter 5. Now substitute a root hair for the thistle tube; the cell content for the molasses; a living plasma membrane for the membrane fastened over the mouth of the thistle tube; and the water in the soil for the jar of water (Fig. 5–5). Inside the cell there are solutions of various substances dissolved in water. Cell vacuoles contain solutions of minerals, food materials, and other dissolved substances. The soil water also contains dissolved minerals, but normally not as much as the cell content. In other words, the concentration of water molecules outside the cell is greater than inside. The soil water is separated from the cell content only by a thin, porous cell wall and the differentially permeable plasma membrane. Can you predict what will happen? Water will move from the soil into the root hair.

Successive osmosis. Now, think of the whole root. The root hair is an outgrowth of an epidermal cell. Inside are many layers of cortex cells. When the epidermal cell takes in water, the concentration of water molecules becomes greater than that of the cortex cell lying against it, so that water passes from the epidermal cell to the cortex cell. As the water content in this cell increases, the next cortex cell receives water from



23-10 Water enters root hairs from the soil by osmosis. It moves through the root by successive osmosis, as osmotic pressure is built up in each succeeding cell.

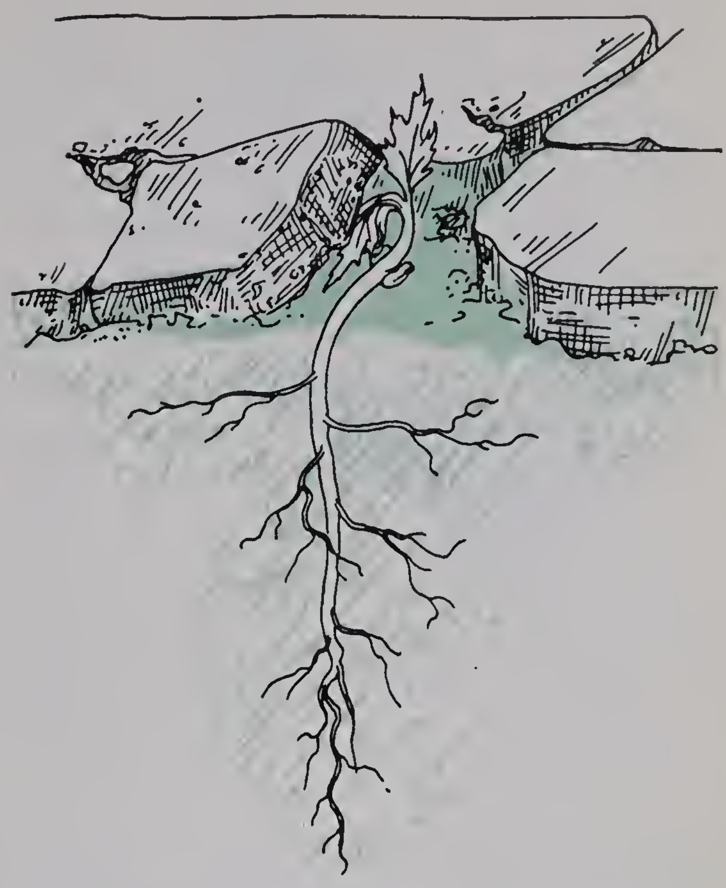
the first, the first one receives water from the epidermal cell. The epidermal cell in turn takes in more water from the soil through its root hair.

This diffusion of water from cell to cell continues to the xylem vessels in the central cylinder of the root. Here water and dissolved minerals move upward to the stem. We may call this cell-to-cell diffusion of water by the name of ***successive osmosis.***

The above discussion is a very much simplified one because the mechanism of water transport is largely a biophysical problem which becomes extremely complicated. To understand it adequately one needs a rather detailed knowledge of both chemistry and physics.

Turgidity in plant cells. In Chapter 5 you learned that as water enters a cell by osmosis, internal water pressure forces the plasma membrane firmly against the wall, causing stiffness known as ***turgor*** (*ter*-ger). When turgor pressure, which would tend to force water molecules out of the cell, becomes as great as the osmotic pressure causing them to move into the cell, osmosis stops. Turgidity (ter-*jid*-i-tee) makes the cell firm, just as you can make a plastic bag rigid by filling it with water. Turgidity in the cells in turn makes the whole plant stiff and firm. It is very important in supporting tender plants whose stems are not stiffened by woody fibers. When turgidity is lost from lack of water, the plant wilts.

When a plant is fully turgid, the pressure in its cells may be as great as 60 to 150 pounds per square inch. Turgor permits the mushroom and the delicate seedling to push through the hard ground. Even concrete has been known to crack from the push of a growing plant, as shown in Fig. 23–11.



23-11 Turgor helps enable a plant to push through surfaces as resistant as cement sidewalks.

Absorption of minerals. Absorption by the root concerns not only the intake of water but the entry of dissolved mineral substances as well. They pass through the membranes of root hairs in solution with water. Together with water they move through the cortex to the inner tissues of the central cylinder where they are conducted to other parts of the plant.

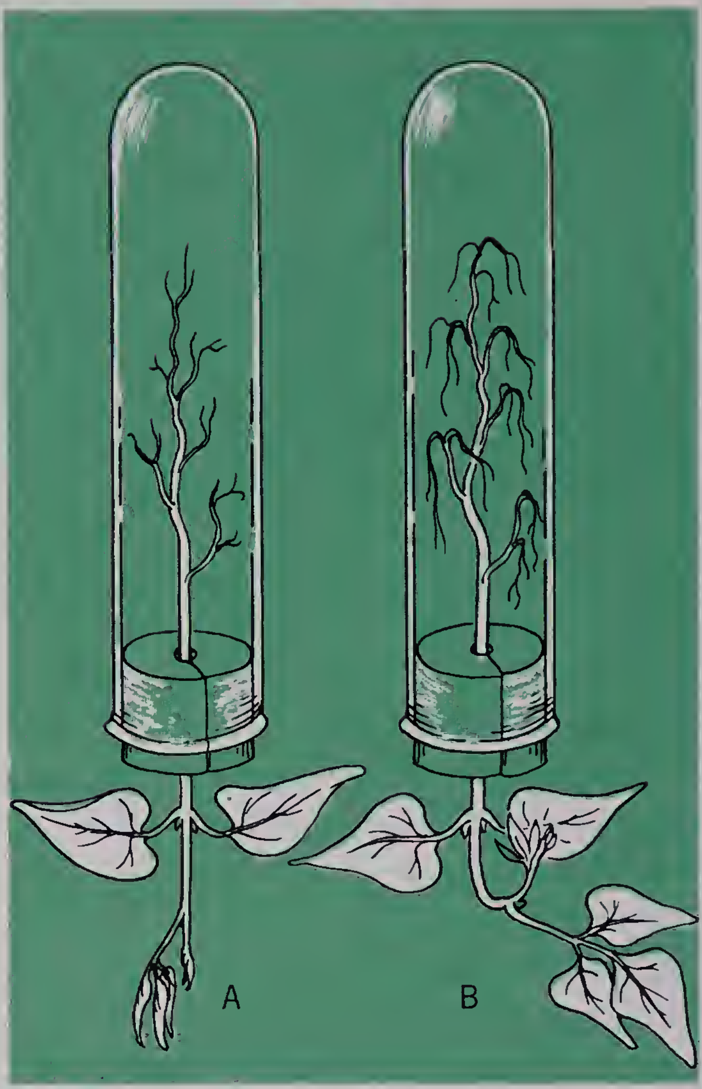
The relation of dissolved minerals to water in the soil solution is very close. Biologists have found evidence that mineral absorption may be independent of water intake. Remember that the concentration of mineral ions must be greater outside the cell than inside if the ions are to enter by diffusion, or passive transport. Root cells, however, absorb mineral ions from soil solutions that contain fewer ions than the cells already contain. Thus, active transport must be operating. In other words, the cells must be actively expending energy in absorbing minerals.

How rapidly do plants absorb soil minerals? A very graphic answer was given to this question by a representative of the Oak Ridge Operations, United States Atomic Energy Commission. During an address on the use of radioisotopes in biology, the speaker produced two potted tomato plants. One was watered with distilled water, the other with water containing a radioactive phosphate (a soil mineral). In less than 45 minutes, the water containing the radioactive phosphate was absorbed through the root hairs of the tomato plant and moved up into the leaves. This was proved by removing a leaf and testing it for the presence of radioactivity with a Geiger counter. The plant had shown no radioactivity at the beginning of the experiment. The control plant showed no radioactivity either before or after the experiment.

Responses of roots to their surroundings. If you happen to plant a seed upside down, will the roots grow out of the soil? Is it mere chance that willow or poplar roots enter cracks in a sewer and clog it with a ball of roots? If a root growing downward strikes a rock, will the rock stop its progress indefinitely?

The various parts of a plant respond, rather rapidly, to certain stimuli in their environment. These responses are growth responses, referred to as ***tropisms.*** External stimuli influence the chemical activity of cells, especially in the regions of roots and stems. As external factors stimulate or reduce the secretion of growth hormones, especially ***auxins***, the rate as well as the direction of growth of the plant organ is influenced.

If the growth response is *toward* the stimulus, as when a root grows toward the earth, we call the response *positive.* On the other hand, a stem shows a *negative* response to gravity when it grows *away* from the earth.



23-12 Geotropism is shown in these drawings. A: the test tube is inverted at the beginning of the experiment. B: after several days.

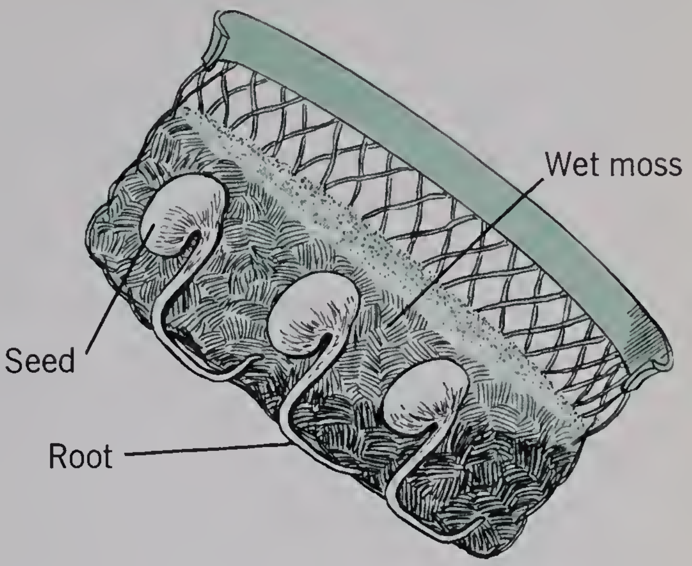
If a stem is lying horizontally, auxins accumulate on the lower side possibly due to the pull of gravity. Growth stimulation on the lower side bends the stem upward. On the other hand, a root placed in the same position bends downward. It would seem, then, that auxins accumulating on the lower side inhibit the growth of root cells. Thus different plant tissues vary in growth response to auxins.

We shall discuss below responses of the root which you may observe in nature or demonstrate in the laboratory.

In discussing tropisms, we must keep in mind the fact that they are automatic growth responses related to hormone secretion. A root does not enter the soil "in order to find water and minerals" or "to get away from the light."

Geotropism. The gravity of the earth is a strong stimulus influencing root growth. It is more than sheer weight that causes the root to grow toward the stimulus of gravity. The stem is equally heavy, and yet it grows away from the earth. *Geotropism* directs the growth of the root toward the earth and its supplies of soil water and dissolved minerals. Without this important response, roots would grow in all directions and only by chance reach these necessary substances. Geotropism is illustrated by the experiment shown in Fig. 23–12.

Hydrotropism. Water is a very strong stimulus and may cause a root to grow toward it from a considerable distance. This response is ***hydrotropism*** (Fig. 23–13). It is shown in the vast number of fine roots that force their way into pipes or spread through the moist topsoil. They grow in these directions in spite of the force of gravity, which attracts them downward. The response of the roots of willows and elm trees makes them undesirable for planting near drains or sewers.



23-13 This experiment shows that water is even a stronger stimulus to plants than gravity.

IN CONCLUSION

The entire contact of a plant with its soil environment depends on a healthy, functioning root system. If this is upset drastically, the plant cannot survive, for the root absorbs water and minerals, stores food, anchors the plant, and sometimes acts as an organ of reproduction.

The root, important though it is, is only one of several different plant organs. True, the average seed plant could not exist without its root system. But it would have just as much trouble living without its stem, as we shall see.

BIOLOGICALLY SPEAKING

adventitious root
aerial root
aquatic root
auxin
central cylinder
cortex
elongation region
endodermis
epidermis
fibrous root
geotropism
hydrotropism
maturation region
meristematic region
pericycle
phloem
plasmolysis
primary root
root cap
root hair
secondary root
successive osmosis
taproot
tropism
turgor
vascular cambium
xylem

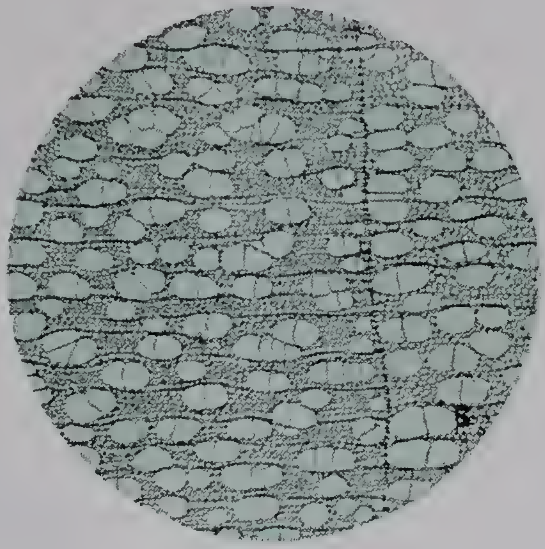
QUESTIONS FOR REVIEW

1. From their origin, distinguish a primary root from a secondary root.
2. Describe the general form of taproot and fibrous root systems.
3. Why is carbonic acid important to the growth of a root?
4. Name four regions of the root tip and discuss the activity of each.
5. Root hairs are sometimes incorrectly called branch roots. Why is it incorrect to speak of a root hair as a branch or secondary root?
6. Name seven tissues of a mature root and state the function of each.
7. Distinguish between adventitious roots and normal roots.
8. Describe several special functions that are performed by adventitious roots.
9. Explain how successive osmosis takes place in the cells of a root.
10. What are some of the responses of roots to their surroundings?

APPLYING PRINCIPLES AND CONCEPTS

1. Hickory trees seem to thrive especially well on dry ridges and hillsides. What kind of root system would you expect these trees to have?
2. A plant dug up with a large ball of dirt has a far better chance of living than one taken out with the roots exposed, even though these roots are not torn off. Why is this true?
3. Roots thicken by adding secondary tissues. How are these tissues formed?
4. Branch roots grow from the pericycle at the outer edge of the central cylinder. Why is the attachment of the branch root to the central cylinder extremely important?
5. Explain the importance of hydrotropism to the life of a plant.
6. Discuss the use of radioactive substances in mineral absorption by roots.

CHAPTER 24



STEM STRUCTURE AND FUNCTION

Herbaceous and woody stems. Those stems that are usually soft and green are classified as ***herbaceous stems.*** Some examples of them are the stems of tomatoes, beans, peas, corn, grasses, and lilies. Herbaceous stems lack most woody tissues that give strength to trees and shrubs. Most herbaceous stems grow relatively little in diameter and last only one season. In plants like the hollyhock, columbine, delphinium, and shasta daisy, the stem is herbaceous and lives for only one season, while the root is woody and perennial. Both the root and the stem are annual in the marigold, zinnia, nasturtium, morning glory, tomato, bean, and pea.

Woody stems, on the other hand, are perennial. They grow in length, increase in diameter, and form new branches season after season. The woody tissues of these stems give them great strength and allow them to reach much greater size than a herbaceous stem.

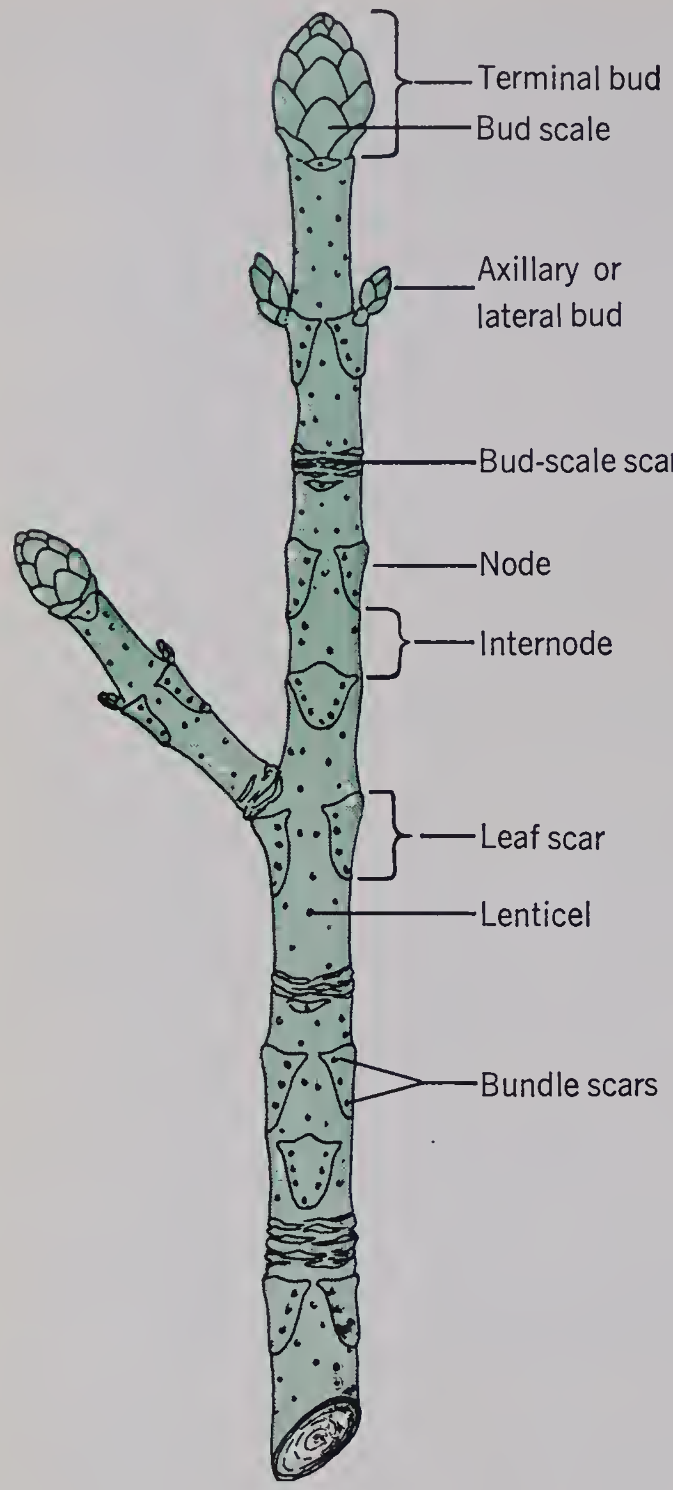
The external structure of a woody stem. The twig of a tree is an ideal subject for study of the external structure of a woody stem (Fig. 24–1). In regions where trees shed their leaves during autumn, a dormant winter twig is especially suitable.

Buds are perhaps the most noticeable structures on the dormant stem. Each bud contains a growing point — a place from which a new stem, leaves, and flowers may develop. In cold climates, winter buds are protected by overlapping ***bud scales,*** which completely enclose the tender growing point. These bud scales serve to protect the delicate tissues inside from drying out and from mechanical damage.

We further classify buds according to their position on the twig. The ***terminal bud,*** not present on all twigs, is located at the tip and contains the terminal growing point of the stem. Along the sides are ***lateral buds,*** from which branches may develop. They are usually smaller than terminal buds and usually different in shape.

At intervals along the twig, circular, oval, or shield-shaped ***leaf scars*** mark the point of attachment of leaf stalks from previous seasons. On the leaf scars minute dots called ***bundle scars*** show the location of the conducting bundles that carried water and dissolved minerals into the leaf from the stem. These bundle scars are of a definite number and arrangement, depending on the species.

You will note in examining the lateral buds that they are usually just above a leaf scar. When the leaf was



24-1 The external structure of a woody stem.

attached to the twig, these buds were in an angle between the leaf stalk and the twig. We call this angle the ***axil.*** Lateral buds produced in the leaf axils are given the special name of ***axillary buds.***

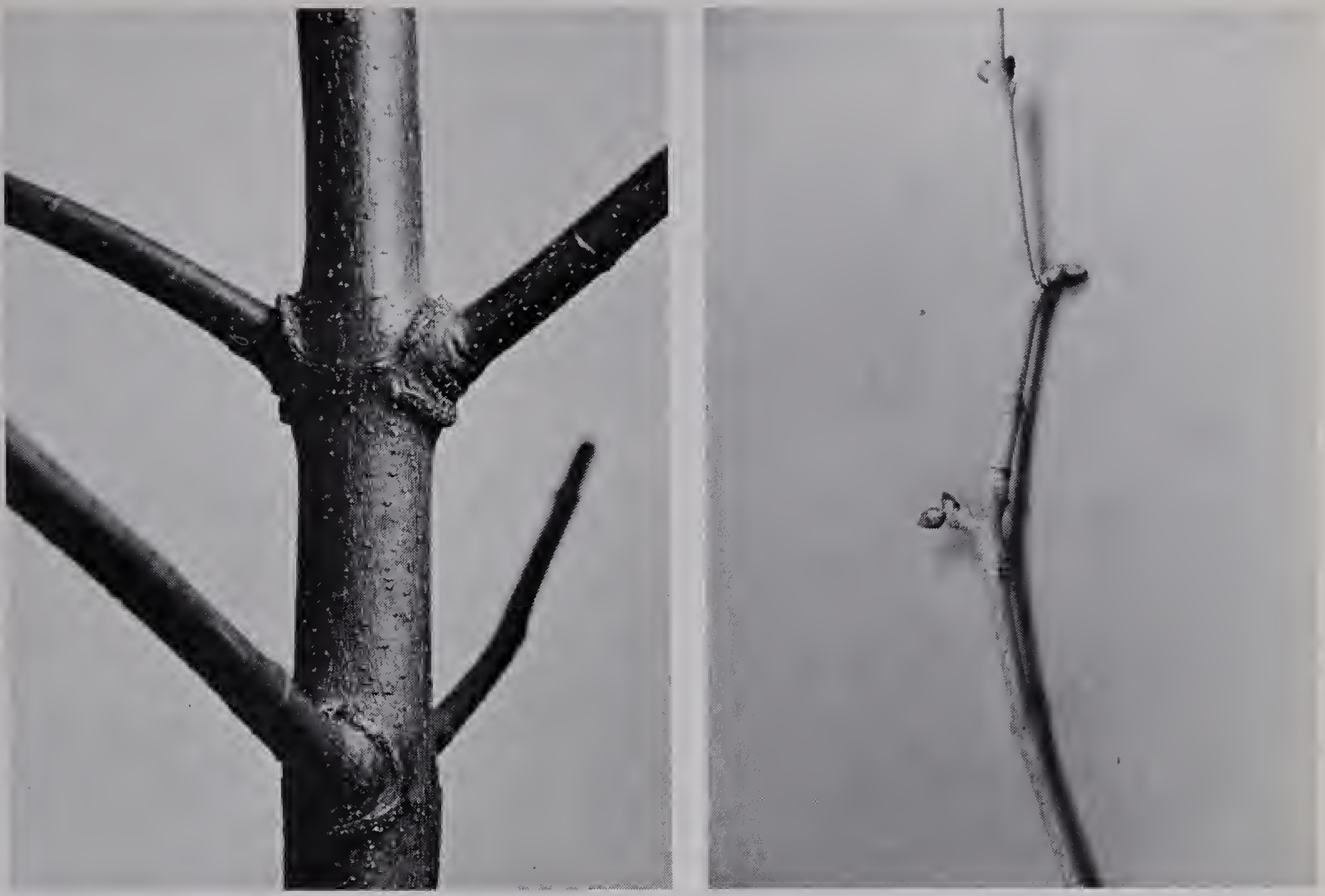
A ***node*** is the point at which leaves or branches are produced from a stem. The space between two nodes is called an ***internode.*** In examining several twigs, note that a single leaf, two leaves, or three or more leaves may develop from a node. If a winter twig has one leaf scar at each node, the leaves are *alternate.* If there are two leaf scars, the leaves are *opposite.* If three or more leaf scars are present at each node, the leaves are *whorled.*

Along the internodes, especially on young twigs, you can see tiny pores called ***lenticels*** opening through the bark. These let air enter and water escape from the twig, especially while it is young and active.

You can find other interesting structures on certain twigs. When terminal buds swell and drop their scales at the beginning of the growing season, a series of rings encircling the twig marks the place where the bud scales were fastened. These ***bud-scale scars,*** at intervals along a twig, show the exact location of the terminal bud during previous seasons. Thus, by starting at the present terminal bud and counting the sets of bud-scale scars along the twig, you can find the exact age of a twig.

Some twigs bear characteristic thorns that make them very easy to identify. These thorns may be either short and broad, long and pointed, or branching. In some species thorns are outgrowths of the epidermis. They may also be modified branches. The thorns of hawthorn trees and the branching thorns of the honey locust are examples of stems modified into protective thorns. The thorns of a rose, however, are outgrowths of the epidermis.

How do stems grow? To show the way in which stems grow, let us assume that a tree is 30 feet high, one foot in diameter, and that the first branch is exactly six feet above the ground. After ten years we return to the tree and find that the trunk is now 16 inches in diameter and 40 feet high. After this period of growth, how far is the first limb from the ground? The answer is *still six feet.*



24-2 The type of branching in a tree depends on the arrangement of the buds. Left: opposite buds produce opposite branches. Right: alternate buds produce alternate branches. (Left: Hugh Spencer; right: Albert Towle)

Growth in length has occurred at the tips of all the branches. The stem regions below the tips have not lengthened at all.

In plants *meristematic regions* are the places where growth begins. Only in these special areas can new cells form as a result of cell division. Furthermore, the growing regions of the stem are of two distinct types: those causing increase in length, and those causing increase in diameter.

Stems grow in length by forming new tissues at their growing points, located in the terminal bud. Branches grow in length as meristematic cells divide and enlarge in the lateral buds. You will remember that such growing points are also found at the tips of roots. The apical growing zone of the stem is somewhat like that of the root, except that it is longer and not protected by a cap. The meristematic region of a stem is microscopic but adjacent to it is a region of cell enlargement which is often several inches long. The corresponding region of the root is only a small fraction of an inch long. As new tissues are produced at the stem tip, they continue to grow until they reach maximum size. Once they have matured, they usually cannot lengthen again. Growth in length is limited to the actively-dividing cells of the growing point.

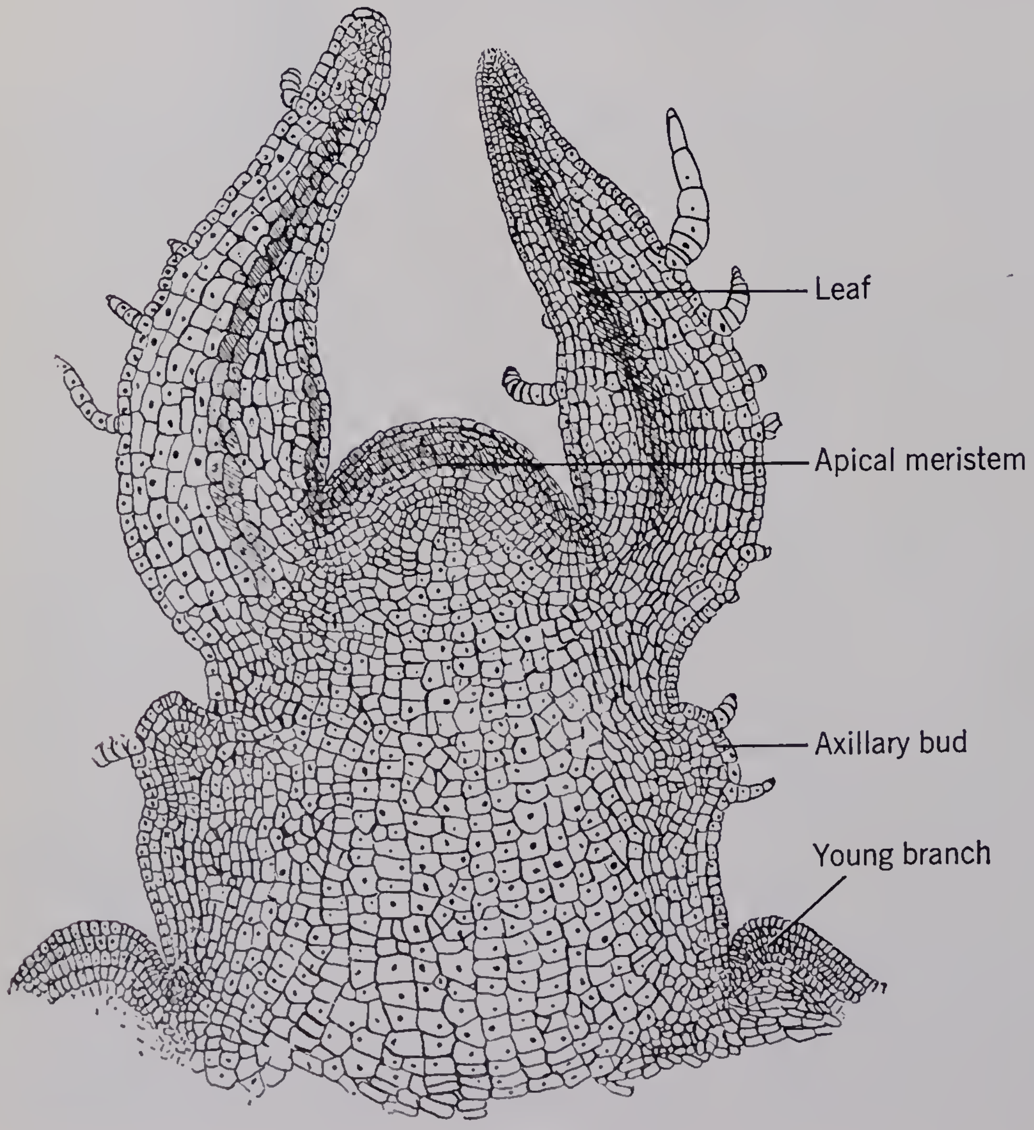
Growth in diameter results from the activity of the *vascular cambium* located deep in the tissues of the stem. We will study this important tissue very soon.

Like growth responses in roots, activity of the growing points in stems is controlled by auxins. Auxin production by the meristematic cells of the terminal bud inhibits the growth of lateral buds, so that the plant does not become too bushy. This effect of the terminal bud on others is called ***apical dominance***. It means, literally, that the bud at the apex (terminal end) dominates the others. A gardener or florist takes advantage of this when he snips off the terminal buds of his plants. This allows the lateral buds to develop, making the plants bushy and producing more flowers.

The growth response to light, called ***phototropism***, is another example of the effect of auxins on stem growth. You are familiar with the fact that the stems of a plant kept on a windowsill will bend toward the light. This bending is caused by the fact that light reduces the production of auxin on the bright side, reducing the growth on this side of the stem. The greater growth on the shaded side causes stems to bend to the light.

Branching patterns. If a young tree has a strong apical dominance and terminal buds of other years escape injury, the main stem will continue upward, forming a central shaft. Branches grow from this as a result of the development of lateral buds. We class such trees, characterized by branches which grow from a central shaft, as ***excurrent*** (Fig. 24–4).

Excurrent branching is shown in the pine, fir, spruce, hemlock, redwood, and cypress. These trees, unless injured or diseased, have a perfect cone-shaped outline. A strong central shaft rises to a point at the tip of the tree. Branches grow horizontally at regular intervals along the stem, decreasing in length from bottom to top. This difference in length is due to a difference in



24-3 Stems grow in length by forming new tissues at their growing points, as this drawing of the longitudinal section of a bud indicates.

24-4 Excurrent branching, where lateral branches arise from the main stem, or central shaft, is characteristic of evergreens such as spruce, fir, pine, and hemlock. They can withstand large amounts of snow without great injury. (U.S. Forest Service)

age, the oldest branches being located at the base, while the youngest are at the top. By counting the number of circles, or whorls, of branches along the trunk, you can tell the age of the tree with reasonable accuracy.

The willow, cottonwood, and elm have quite a different form of branching. These trees produce a single trunk, which divides, usually rather low, to form several large branches. The effect is a spreading pattern of growth classed as ***deliquescent*** (del-i-*kwes*-nt) [Fig. 24–5]. This growth results when twigs lack strong apical dominance, so that lateral buds form branches that equal or exceed growth from the terminal bud. In trees like the buckeye, horse chestnut, and magnolia, terminal buds develop flower clusters. Lateral buds form branches, resulting in a spreading, deliquescent pattern.

Branching form often determines the timber value of trees. Quite obviously, trees having excurrent branching far exceed in timber value those having deliquescent branching. The characteristic growth of pine makes it ideal for lumber, while spruce and fir are suitable for telephone poles, furniture, shingles, and many other lumber products.

In the oak, walnut, hickory, maple, and other forest trees, long trunks develop under forest conditions, although the same trees branch more freely in open places. Foresters have found that the best timber trees are the types found growing in dense stands.

The internal structure of a woody stem. If you cut a young branch of a tree, you can see three distinct regions, as shown in Fig. 24–6. The outer region is the bark, which is quite distinct from the area of wood occupying the middle part of the stem. The center of the stem is called the pith, although it is hard to find the pith of a large tree because it is so very small in comparison with the large amount of wood. A fourth region, the vascular cambium, lies between the bark and the wood and consists of a very thin layer of delicate tissue. This is almost impossible to see without a magnifying glass.

The wood in an old stem often appears to be of two types. The outer area is usually light in color and consists of active, functioning wood, or *sapwood.*

24-5 An elm tree illustrates deliquescent branching in which the older branches arise from the central shaft and many new branches arise from other branches. (Saunders from Monkmeyer)

Sapwood is absolutely necessary for the tree to live. Next to the sapwood is a cylinder of darker wood called ***heartwood.*** This occupies the center of the stem and surrounds the cavity where the pith originally was. The tissues composing the heartwood are dead and often filled with gums, tannins, or resins which give it a characteristic dark color. Heartwood is not active in water transport but it does contribute to support for a tree. It is the portion of the tree that is used in making the finest quality of furniture.

Annual rings form circles through the wood, one outside the other, and mark each season's growth of wood. You can determine the approximate age of a stem by counting them. The ***pith rays*** appear as lines radiating to the outside of the wood like the spokes of a wheel. Some types of wood, such as oak, show especially prominent rays.

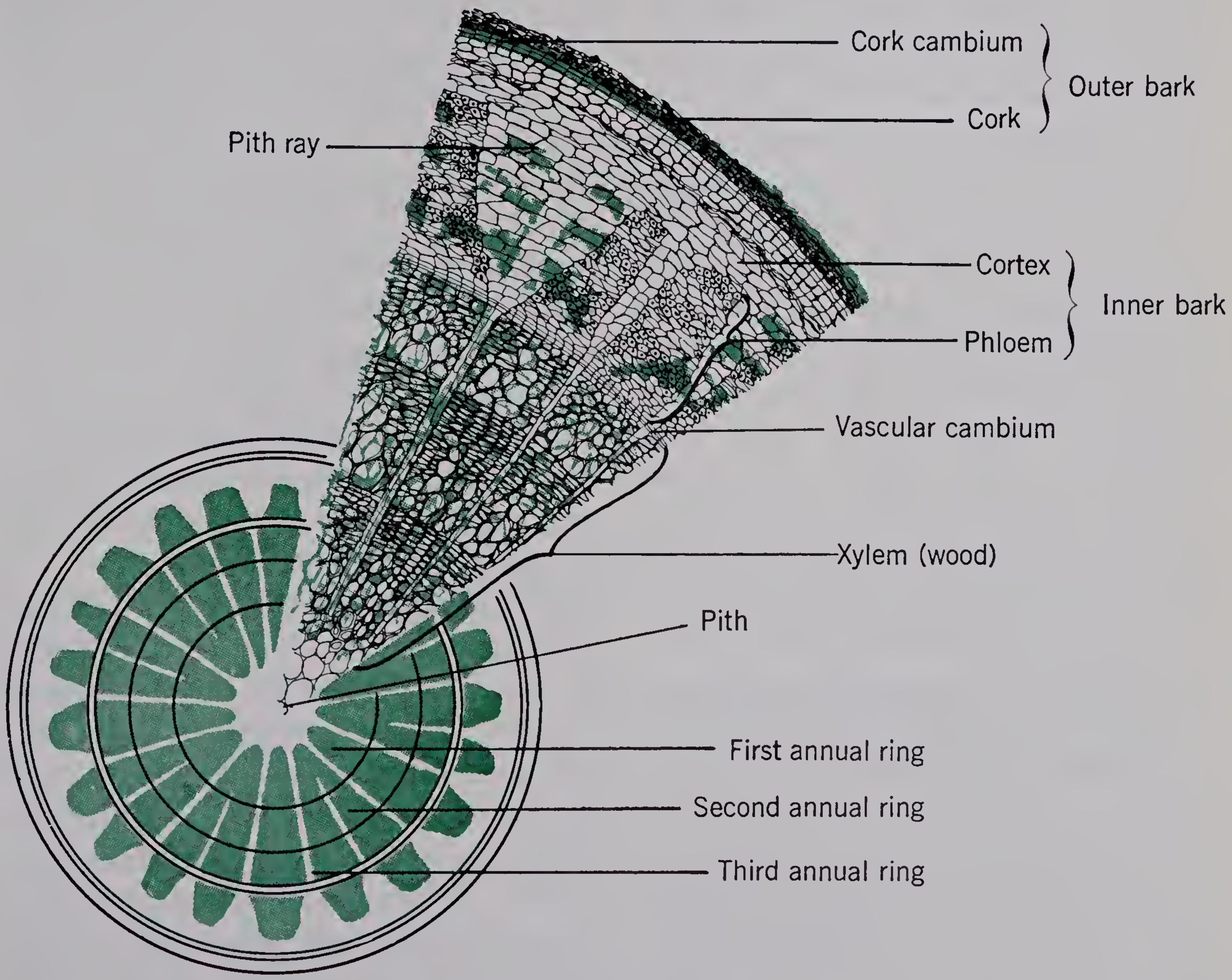
Bark – its structure and activity. The term ***bark*** includes much more than just the outer covering of a tree. It is a region of the stem composed of several kinds of tissues.

A young twig is covered for a time by a thin epidermis that protects the young stem from injury and disease. Soon, however, the epidermis is replaced by a tissue called ***cork,*** which forms the outer covering we see on a branch or tree trunk. Cork is composed of dead cells arranged in layers. It protects the stem from mechanical injury, from disease, and from loss of water.

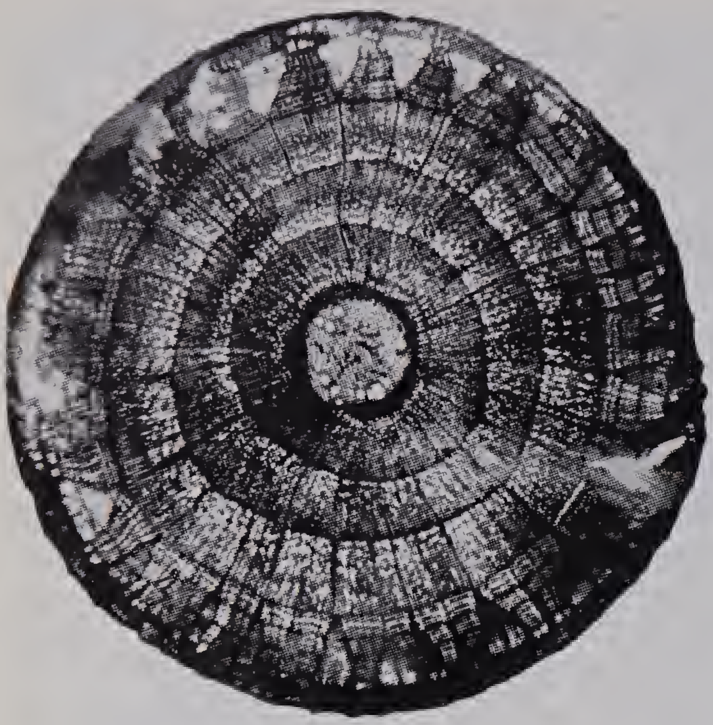
As stems grow in diameter, the outer corky layer splits, so that it is constantly renewed. New cork is produced by a special layer of cells called the ***cork cambium.*** The cells that compose the cork cambium divide frequently and add new cork on the inside as it is destroyed on the outside. The structure of the cork cells and the continual splitting of the cork layer due to the growth of the stem result in the characteristic appearance of tree trunks — scaly, peeling, grooved, or fissured. The cork tissue of a tree is often called the *outer bark.*

Inside the cork and cork cambium lie two other important bark tissues composing the *inner bark.* The outer one of these, the ***cortex,*** is composed of large thin-walled cells arranged like stones in a wall. In young stems the cortex cells contain chloroplasts and carry on photosynthesis. As the stem matures and cork begins to form, this function ceases, and the cortex disappears.

Inside the cortex lies the innermost layer of bark, the ***phloem.*** This important tissue conducts food from the leaves to the various parts of the plant. Phloem consists of several different kinds of cells. ***Sieve tubes*** are the most prominent, appearing as rows of rather large, elongate living cells that have thin walls and protoplasm but no nucleus. Their end walls, and sometimes their side walls, have small openings through which sap, containing dissolved food substances, flows easily. Next to and bordering on sieve tubes are long,



24-6 Diagram of the internal tissues of a three-year-old woody dicot.



24-7 A cross-section of a three-year-old linden stem. (Walter Dawn)

narrow ***companion cells,*** which are also living and which have nuclei. Just how these companion cells aid in food conduction is not clear, but they are always present in phloem tissue. Additional cells found in phloem are ***phloem fibers,*** which are slender, long cells with thick walls, and ***phloem parenchyma*** cells, in which food is temporarily stored. Linen is made from the fibers of flax plants, rope from those of Indian hemp.

Activities of the vascular cambium. A ring of embryonic cells between the bark and the wood, known as the ***vascular cambium,*** is responsible for all increase in diameter of the stem. During the spring and summer this cambium is active in producing new cells by division. It forms new phloem tissues on its outside surface and new wood tissues on its inside surface. During one season of cambium activity, many more wood cells than phloem cells are formed. That is why the wood area of a tree is always much greater than its bark thickness.

The tissues composing wood. Wood, or *xylem* tissue, serves two main functions: conduction of water and dissolved minerals upward, and support, and they have special adaptations for these duties. The largest xylem elements are the ***vessels,*** which are long tubes made up of nonliving cells joined end to end, with large openings in their end walls. Thus liquids can move easily from cell to cell in a continuous stream. Next come the ***tracheids*** (*tray*-kee-idz), which are long and narrow and which die at maturity. They have rather heavy cell walls which contain lignin and other substances which give extra strength. In the walls of tracheids are small unthickened areas called *pits.* Because of the pits tracheids are able to participate in the conduction of water from cell to cell. With their very thick walls ***xylem fibers*** contribute to the strength of wood. ***Xylem parenchyma*** cells serve as storage cells. Pith rays are different from the other stem tissues in that they contain protoplasm and a nucleus. They conduct liquids laterally rather than up or down.

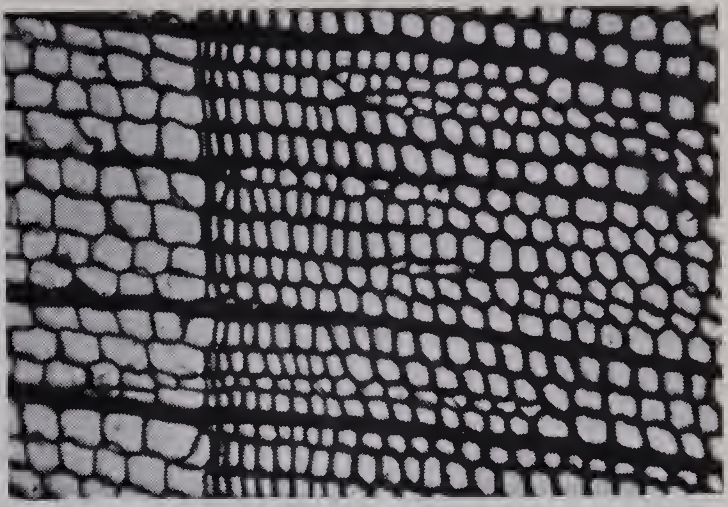
As woody stems increase in thickness year after year, the wood formed by the cambium is arranged in layers. Frequently, the cambium produces two kinds of wood during the season: ***spring wood,*** containing many large vessels mingled with tracheids and fibers; and ***summer wood,*** containing few vessels and large numbers of fibers (Fig. 24–8). This difference in texture between spring and summer wood results in layers that appear as the annual rings.

The pith region of the stem. The central core of ***pith*** is scarcely noticeable in an old woody stem. In the young stem, however, the pith occupies a proportionally large area and serves as an important place of storage. Since pith is not produced by the cambium, it never increases in size. Regardless of the size to which a tree may grow, its pith never increases beyond the amount present during the first year of growth.

The table below summarizes the various tissues of the woody stem and their functions.

The structure of a herbaceous stem. Herbaceous stems differ from woody stems chiefly in having much less xylem and phloem tissue. These two occur in most herbaceous stems in the form of long strands called ***vascular bundles*** which run lengthwise through the stem.

In our introduction to the seed plants, we noted that the flowering plants are divided into two large subclasses — the Monocotyledonae and the Dicotyledonae, according to the number of seed leaves. Examples of ***dicots*** are



24-8 The cells at the left of this photomicrograph were produced in the spring, while those at the right were formed during the summer months. The so-called line between them is an annual ring. (International Paper Company)

SUMMARY OF STRUCTURE AND ACTIVITIES OF A WOODY STEM

Region	*Tissue or Cell Type*	*Activity*
Bark	Epidermis (only on young stems)	Protection, reduction of water loss
	Cork	Protection, prevention of water loss
	Cork cambium	Production of cork
	Cortex (only in young stems)	Storage and food manufacture
	Sieve tubes	Conduction of food, usually downward
	Companion cells	Uncertain
	Phloem fibers	Support
	Phloem parenchyma	Storage
Vascular cambium	Meristematic cells only	Formation of phloem, xylem (wood), and rays
Wood	Xylem vessels	Conduction of water and minerals upward
	Tracheids	Conduction and strengthening of wood
	Xylem fibers	Support
	Xylem parenchyma	Storage
	Pith rays	Conduction laterally
Pith	Parenchyma	Storage

24-9 The approximate age of a tree may be determined by counting the annual rings in the trunk. (U.S. Forest Service)

the tomato, buttercup, and bean. The *monocots* include the iris, orchids, lilies, grasses, sedges, and corn. The herbaceous stems of these two groups show definite differences in structure, especially in the arrangement of their *fibrovascular bundles.*

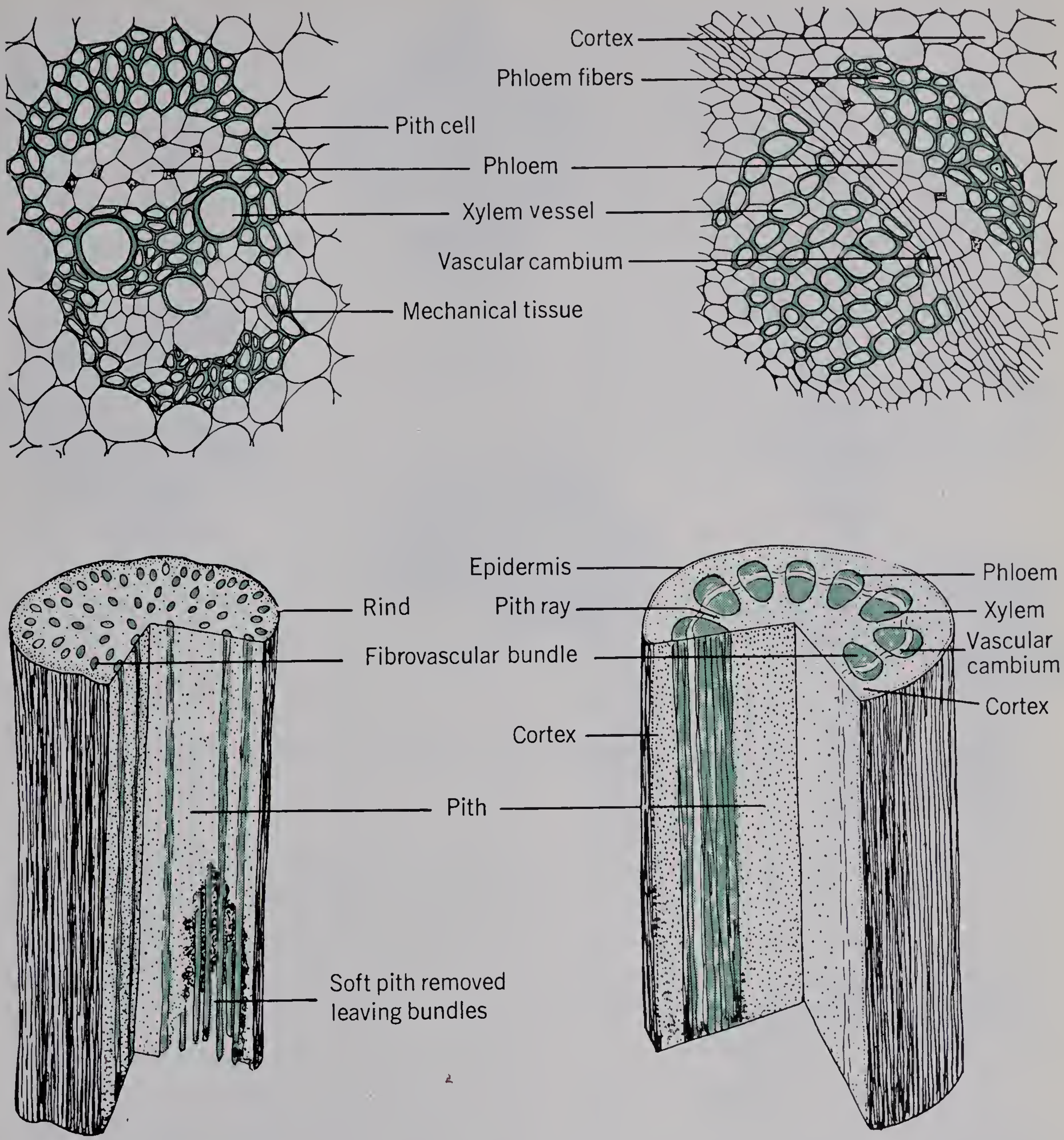
The herbaceous dicot stem. If you section the stem of a herbaceous dicot plant (your teacher will tell you a good one to use in your community), you will see several distinct regions. The outer layer of the stem is a thin epidermis, which serves for protection. Inside the epidermis is a layer of cortex, composed of loosely-packed cells, often containing chlorophyll. These manufacture food as well as store it. Within the cortex, the vascular bundles occupy a ring-shaped zone. These bundles contain xylem and phloem tissues. In some species the bundles are more or less fused together into a continuous ring. In others the bundles are separated from one another by broad pith rays.

Many herbaceous dicot stems develop a vascular cambium that consists of a ring of cells extending through the bundles. The vascular cambium separates the phloem in the outer portion of the bundle from the xylem tissues within. The activity of this cambium in producing new phloem and xylem cells results in an increase in the diameter of the stem. But the herbaceous dicot stem does not live through the winter in cold climates, so the growth in diameter of the stem is only for one season.

The structure of a monocot stem. If you cut a section across a corn stem, you will find the tissues very differently arranged from those in the dicot stem. The outer covering is a tough epidermis composed of thick-walled, hard cells. Its functions are to support the plant and to protect the other stem tissues. The bulk of the stem consists of a pith whose cells have thin walls. Through the pith you will see numerous fibrovascular bundles scattered rather than arranged in a ring. In other words, monocot stems have scattered bundles while dicots have their bundles in a ring.

Monocots lack a cambium, so that they usually grow in diameter only until their cells have reached a maximum size. This is why they are generally long and slender as in the iris, orchids, lilies, grasses, and sedges. Their leaves often have sheathed bases that wrap around the stems from one node to the next lower one.

Some stem adaptations. Although we think of a stem as growing entirely above the ground, not all of them do. Some are entirely underground, and what we see exposed to light are merely clusters of leaves. Various environments may cause certain adaptations as in the iris or lily of the valley, whose fleshy underground stems are called ***rhizomes.*** The


Cortex
Phloem fibers
Pith cell
Phloem
Xylem vessel
Vascular cambium
Mechanical tissue
Epidermis
Rind
Pith ray
Phloem
Xylem
Fibrovascular bundle
Vascular cambium
Cortex
Cortex
Pith
Soft pith removed leaving bundles

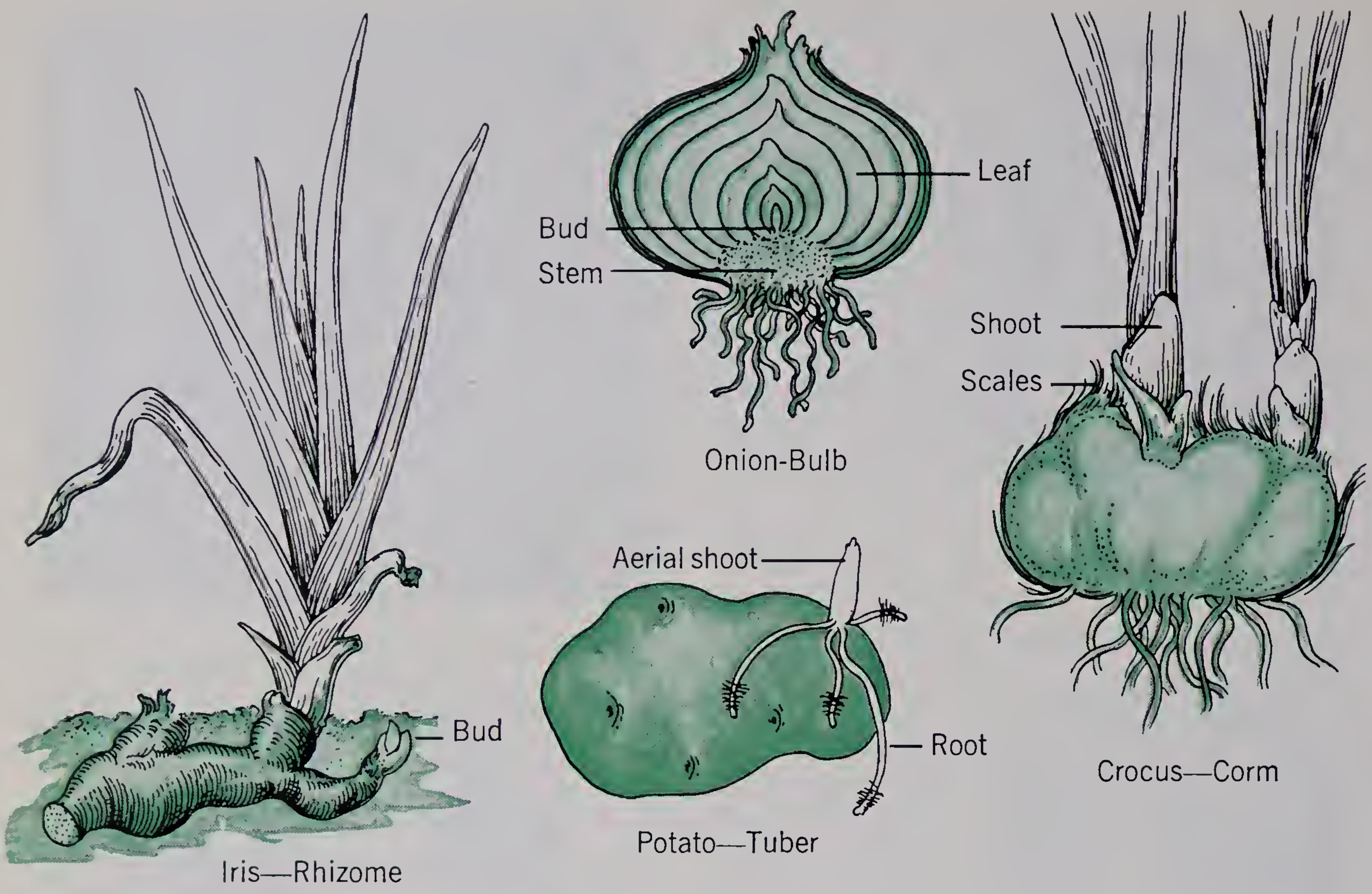
MONOCOT STEM AND BUNDLE

HERBACEOUS DICOT STEM AND BUNDLE

24-10 Compare these longitudinal and cross-sections of a monocot stem (corn) and herbaceous dicot stem (bean). How do they differ?

potato is an enlarged rhizome called a *tuber*, which is swollen with stored food. The "eyes" of a potato are buds. A *bulb* is actually an underground bud, with the stem of the plant reduced to a small disk at the base of the bulb surrounded by leaves. Daffodils and tulips are examples of plants having bulbs. The *corm*, found in the gladiolus and crocus, is different from the bulb in that most of its stem is covered with thin scales.

Many stems, though they grow above the ground, differ from ordinary erect stems in their special adaptations. The shortened stem of the carrot, for example, is disk-shaped and grows just above the root. Creeping stems, such as occur in the strawberry, represent a special adaptation for propagation.



24-11 Here are four types of underground stems. Why are they stems rather than roots?

Climbing stems also lack woody tissue, and may twine around an object for support or produce tendrils that serve as a means of grasping. The pole bean and morning glory twine, while the pea forms tendrils.

In short, stem adaptations make possible the growth of plants in various environments and enable them to compete favorably with other members of the community. Figure 24–11 shows some of these stem adaptations.

Plant propagation by means of stems. While conduction, support, and storage are the most outstanding functions of a stem, reproduction of plants by stems is another function. Such propagation may occur either naturally or artificially.

Layering occurs naturally in many plants when a stem comes in contact with the ground. At the point of contact roots develop. If the stem is severed, it becomes a fully independent new plant. Horticulturists use layering as a means of multiplying many plants.

As you are no doubt aware, the stems of many herbaceous plants and some woody plants can be rooted by placing them in water or moist sand. We call these rooted stems *cuttings*. This is an important means of propagation by stems.

Grafting consists of bringing into close contact the vascular cambium of a live, dormant twig and the vascular cambium of the tree on which it is to grow. This can be accomplished by tapering the end of the twig, or ***scion*** (*sy*-on), to be used and inserting it into a slit prepared in the rooted branch, or ***stock***, which is to receive the graft. Such a graft can be successful *only if the vascular cambiums of both scion and stock are united with each other*. Also, grafting is successful only when stems of the same species or closely related species are united. We cannot graft an apple twig to an oak tree, but we can graft several varieties of apple trees onto a single apple stock.

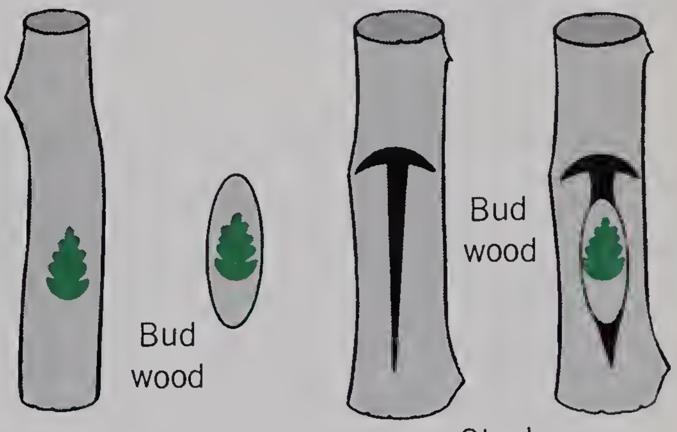
Budding is similar to grafting except that a bud rather than a twig is united with the stock (Fig. 24–12). In budding, a vigorous bud is selected and removed with a piece of bark surrounding it. The bud is united with the stock by slipping the piece of bark under the bark of the stock, which has been loosened by a T-shaped cut. This unites the vascular cambiums of scion and stock. In both budding and grafting, the wound resulting from the operation should be covered with wax to prevent the entrance of bacteria and fungi, and to prevent local drying.

Pruning woody plants. When we cut excess branches from trees and shrubs the process is ***pruning.*** It is done to change the shape of the plants, to produce more and better quality of fruit, to remove dead or diseased wood, and to enable the plant to recover more easily after being transplanted. It is best to prune in winter when the sap is not rising in the stem.

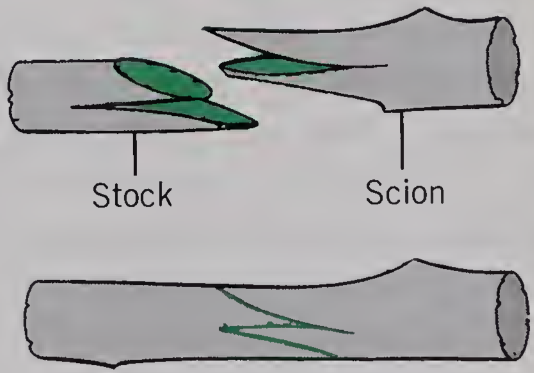
Movement of water in the stem. We can understand how water and minerals can rise from the roots to the leaves of a small plant. But what about a column of water rising 300 or more feet up the trunk of a huge forest tree? The answer to this question is not completely known, but biologists agree that at least four forces are involved.

You found in the study of water absorption by the root that root cells normally have a high osmotic pressure. As water passes from the cells to the xylem vessels extending through the root and stem, it is forced upward with considerable force. This force is great enough to push water to the leaves of a small plant. It can be observed in many plants when the stem is cut off and water bleeds from the severed xylem vessels of the stump. However, ***root pressure*** alone could force water but a short distance through the stem of a tall plant.

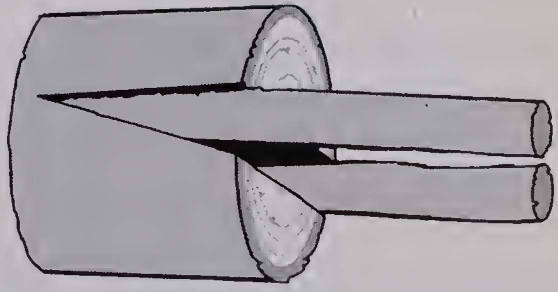
In Fig. 24–13 we see a second force known as ***capillarity.*** When the end of a small tube is placed in a liquid, the liquid rises in the tube to a level above that at which it stands in the larger container. The smaller the inside diam-



Budding

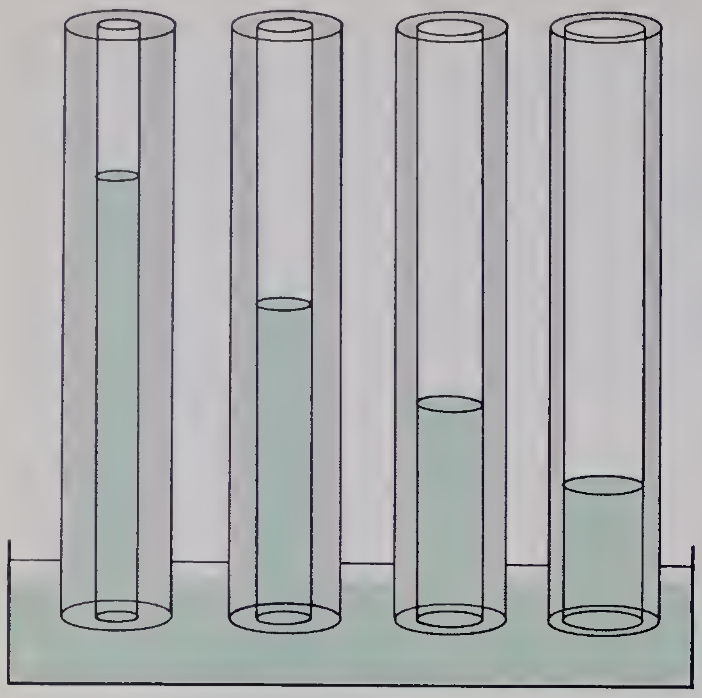


Whip grafting



Cleft grafting

24-12 Budding and two types of grafting.



24-13 Each of these tubes has a bore of a different size. In which one do you think water will rise the highest?

eter of the tube, the higher the liquid will rise. This rise is due to the attraction of the liquid by the surface of the tube. If you substitute the many tiny xylem vessels in a stem for the capillary tubes, you can see why water rises in a stem, even when it is cut off and placed in a container of water, as in a bouquet of flowers.

Biologists believe that the greatest force involved in the rise of water through a stem is a pull rather than a push. This force is called the ***transpiration pull.*** During transpiration, leaves lose water to the atmosphere by evaporation. As the cells closest to the atmosphere lose water, they in turn take water from the cells adjacent to them. Thus a flow of water passes through the leaf tissues to the atmosphere. As water is lost from the leaves, a continuous column, extending from the leaf through the branches and trunk, is lifted upward.

The lifting of a column of water involves still another force, ***cohesion.*** You are demonstrating cohesion when you draw a liquid up through a soda straw. As you remove liquid at the top of the straw, you create a partial vacuum. To fill this vacuum a column of liquid rises through the straw. The particles of the liquid cling together by cohesion. Cohesion results in the lifting of columns of water and dissolved substances through the xylem vessels of roots and stems, as water is drawn upward by transpiration pull.

The movement of foods in stems. The movement of dissolved foods in plants, chiefly through the phloem sieve tubes, is referred to as ***translocation.*** The forces involved in this movement are not fully understood. The usual direction of food translocation is from the leaves downward through the phloem. However, the movement may be upward from the leaves to flowers and developing fruits situated above the leaves. Furthermore, early in the spring, sap containing dissolved foods moves upward from places of storage in the roots and lower stem region to the branches and developing buds of perennials.

The movement of foods is too rapid to be explained by diffusion from one phloem cell to another. Other forces must be involved. Some biologists believe that the pressure in the phloem cells decreases from the leaves through the stem, thus causing a flow toward the cells of lower pressure.

IN CONCLUSION

The stem is a remarkable organ. One might say that it is a jack of all trades, for it functions as an organ of conduction, support, storage, and even reproduction.

Equally marvelous is the leaf, as you shall see in the next chapter. This chemical factory lays the foundation for the entire living world by giving it the basic food necessary for the maintenance of life.

BIOLOGICALLY SPEAKING

annual ring
apical dominance
axil
axillary bud
bark
bud
bud scale
bud-scale scar
budding
bulb
bundle scar
capillarity
cohesion
companion cell
cork
cork cambium
corm
cortex
deliquescent
dicot
excurrent
fibrovascular bundle
grafting
heartwood
herbaceous stem
internode
lateral bud
layering
leaf scar
lenticel
monocot
node
phloem fibers
phloem parenchyma
phototropism
pith
pith rays
pruning
rhizome
root pressure
sapwood
scion
sieve tube
spring wood
stock
summer wood
terminal bud
tracheid
translocation
transpiration pull
tuber
vascular cambium
vessel
woody stem
xylem fibers
xylem parenchyma

QUESTIONS FOR REVIEW

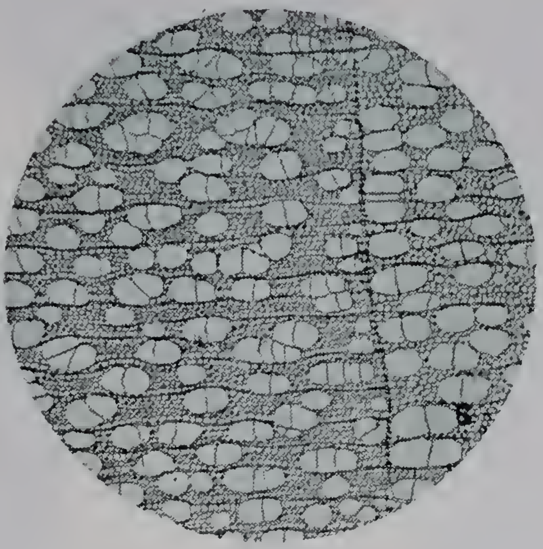
1. Distinguish between herbaceous and woody stems, and give examples.
2. From what danger do bud scales protect the growing point of a twig during the winter season?
3. Explain how the branching pattern of a tree is determined by apical dominance.
4. Distinguish between sapwood and heartwood in regard to appearance and use to the tree.
5. Name four tissues found in the bark region of a woody stem, and list the functions of each tissue.
6. Explain how the cambium causes increase in the diameter of a woody stem.
7. In what direction are water, minerals, and dissolved foods moved through the pith rays of a stem?
8. In many stems, spring wood is easily distinguished from summer wood. Describe the difference in structure in these types of wood.
9. What three tissues form the fibrovascular bundles of herbaceous stems?
10. How can a herbaceous dicot stem be distinguished from a monocot stem by the arrangement of its fibrovascular bundles?

11. Name three underground stems and give an example of a plant producing each type.
12. Of what advantage to the plant is a twining stem?
13. What two tissues of a stem must be united if a graft is successful?
14. Name and define four forces operating in water movement through stems.

APPLYING PRINCIPLES AND CONCEPTS

1. Compare the way in which a tree grows with the growth of your body.
2. Why are forest-grown timber trees more valuable than the same species grown in open places?
3. Rabbits, beavers, horses, and deer often chew the bark of young trees. If they destroy the bark all the way around on a portion of the trunk, the tree usually dies within a few weeks or months. Explain.
4. Most plants with shortened stems grow in open fields or prairies. Why?
5. When the leaves of a tree drop off in the fall, much of the upward movement of water and soil minerals through the stem ceases. Explain why.

CHAPTER 25



LEAF STRUCTURE AND FUNCTION

The leaf — a specialized organ for photosynthesis. In Chapter 6 you learned that the living world is powered by sunshine. This energy from the sun converts raw materials into food substances in the green plant cell by the process of photosynthesis. Although some cells in the stem are green and therefore carry on photosynthesis, the leaf cells are the principal food makers of the plant. The leaf is, in fact, a specialized organ for photosynthesis. If we examine a typical leaf for a moment we will see what a perfect organ it is for its function.

A leaf consists of a thin green portion called the ***blade.*** The blade may vary in size and shape from species to species, but it is always distinctive for each species. The blade is strengthened by a network of ***veins,*** which are really vascular bundles entering from the stem, much as blood vessels branch and rebranch in reaching all the tissues of our bodies. In addition to strengthening the blade, the veins carry water, dissolved minerals, and food materials between the leaf and the stem.

Usually the blade is attached to the stem by a stalk, or ***petiole*** (*pet*-ee-ohl). At its base the petiole joins the stem at a node. Some leaves have no petiole. Instead the blade is fastened directly to the stem.

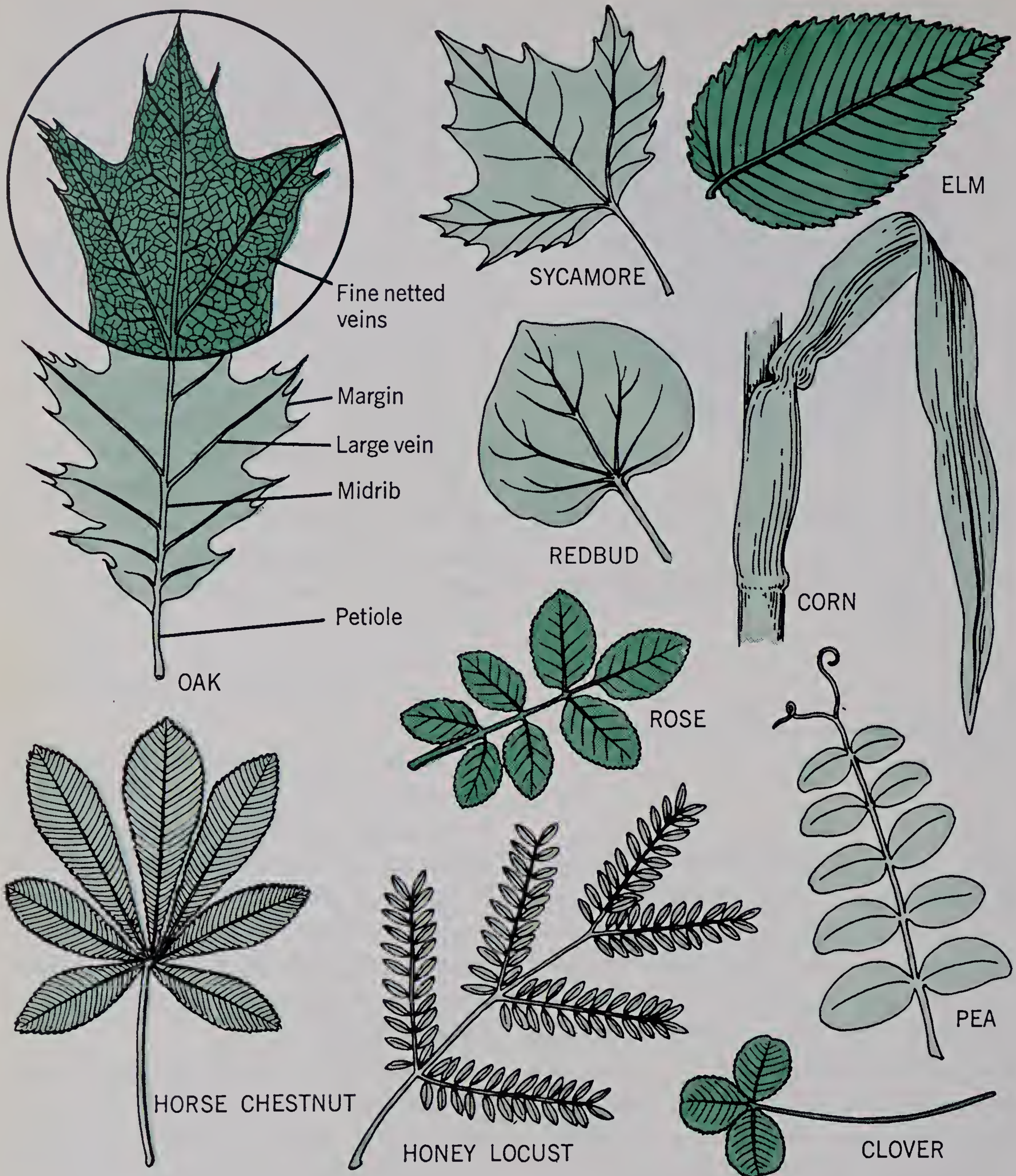
In most leaves, the principal veins tend to be arranged in one of three general patterns. The sycamore leaf shows an arrangement in which several large veins branch out from the tip of the petiole, in much the way your fingers extend from your hand. This pattern is called ***palmate venation*** (Fig. 25–1).

Other dicotyledonous leaves, like the willow and elm, have a single, large vein called a ***midrib*** extending through the center of the blade from the petiole to the leaf tip. Smaller veins branch from the midrib and run to the margins. This second pattern of venation, resembling the structure of a feather, is called ***pinnate venation.***

Most monocotyledonous plants, like the grasses, lilies, and iris, have several large veins running parallel from the base of the leaf to the tip. This third pattern is called ***parallel venation.***

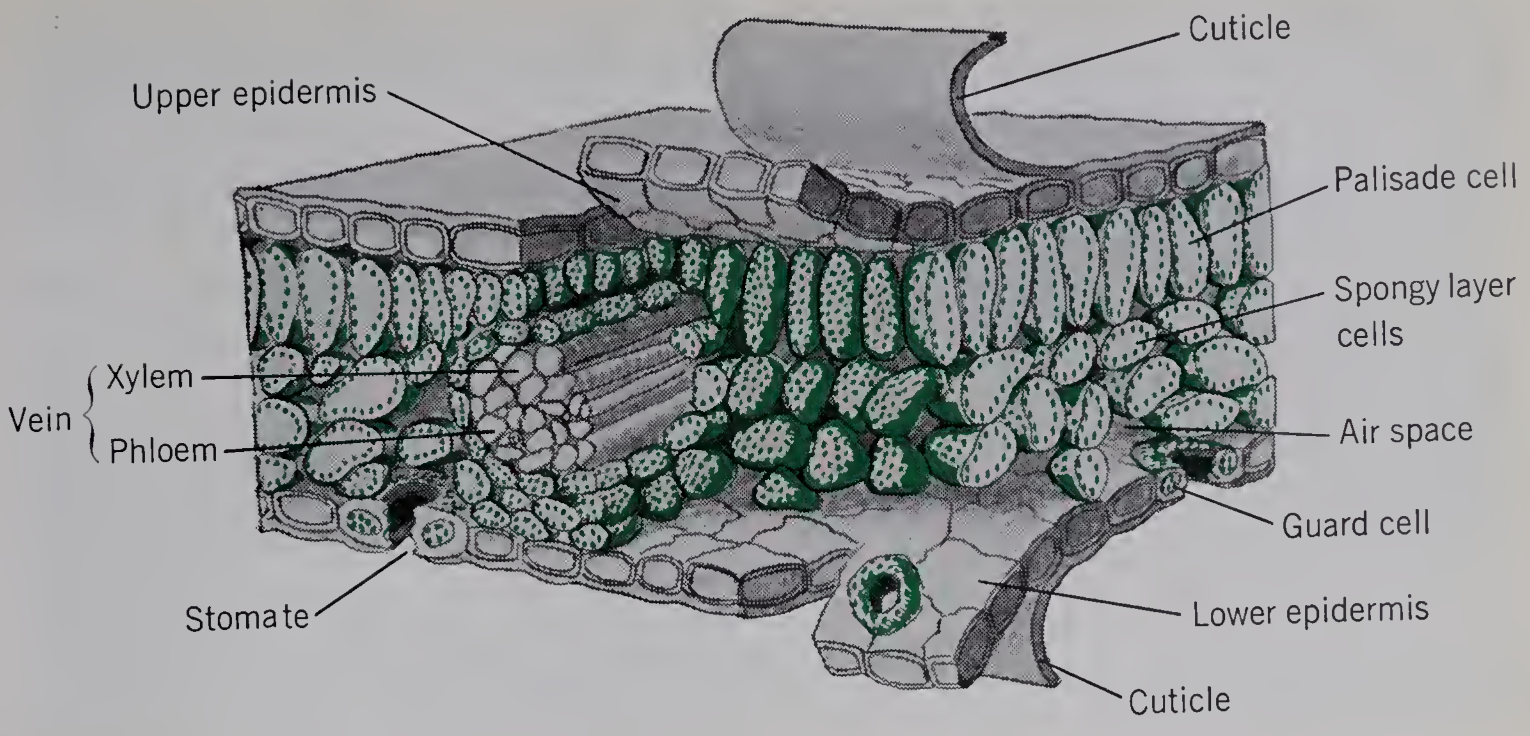
The outline of a leaf depends somewhat on the arrangement of its veins. If the veins are parallel, the leaf is usually long and slender. The forms of the leaves are almost as varied as the kinds of plants. Some have entire edges (lily), others are toothed (elm), lobed (maple), or finely divided (carrot).

When the blade of the leaf, even though greatly indented, is in one piece,


Fine netted veins
Margin
Large vein
Midrib
Petiole
OAK
SYCAMORE
ELM
REDBUD
CORN
ROSE
PEA
HORSE CHESTNUT
HONEY LOCUST
CLOVER

25-1 Numerous veins conduct water to every part of a leaf. Identify the various types of venation and compounding shown in this drawing.

it is called a ***simple leaf.*** There are many leaves, however, in which the blade is divided into two or more parts. Such a leaf is said to be ***compound,*** and each separate part of the blade is called a ***leaflet.*** When the leaflets radiate from a common point, as in the clover and horse chestnut, the leaf is *palmately* compound. When the leaflets are arranged opposite one another, as in the black locust or hickory, or alternate on the sides of a single midrib, the leaf is *pinnately compound.* In certain leaves it may not always be easy to tell whether



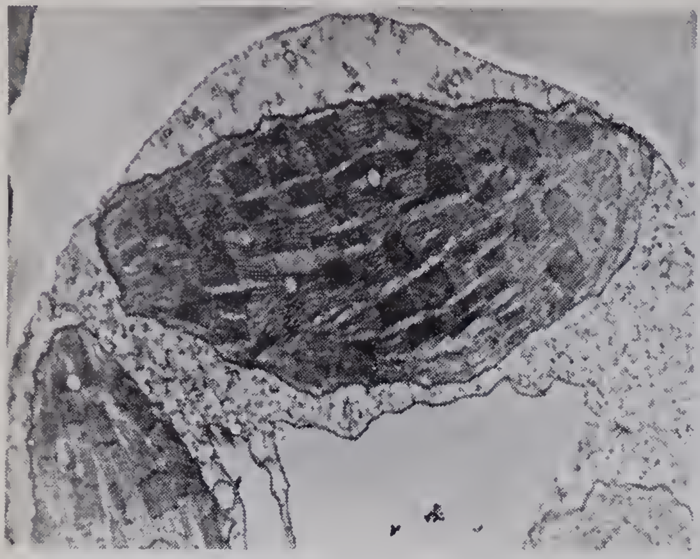
25-2 This drawing represents the cross-section of a leaf with the cuticle and epidermis folded back to show the various tissues.

the part is a leaflet of a compound leaf or the blade of a simple leaf, except in the fall when the whole leaf falls away at the petiole.

Tissues of a leaf. If you cut across the blade of a leaf and study it under a microscope, you will see three distinct tissues. The first of these, the ***epidermis,*** consists of a single layer of cells, one along the top of the blade and one along the bottom. The cells of the epidermis are covered by a layer of wax called ***cuticle,*** which helps prevent loss of water. The lower epidermis contains numerous small pores called ***stomates,*** which regulate the passage of gases to and from the inside of the leaf.

The ***mesophyll*** occupies the largest area in the blade, and in its cells photosynthesis occurs. The mesophyll contains two regions. The first of these is made up of closely arranged, elongated parenchyma cells with many chloroplasts, called ***palisade*** cells. Chloroplasts must be exposed to light, since the chlorophyll they contain is essential to food formation. But too much light destroys chlorophyll. The shape of the palisade cells permits the greatest light transmission throughout the length of the cell. Below the palisade layer is a layer of loosely packed parenchyma cells called ***spongy*** cells with large air spaces between them. Note that these air spaces are connected to the outside atmosphere by the stomates. The veins, containing xylem and phloem tissue, are scattered through the spongy tissue. They carry water and food materials and help to support the blade.

The stomates. The pores called stomates are only about one twentieth as wide as this paper is thick. On each side of the pore is a bean-shaped ***guard cell*** containing chloroplasts. The guard cells regulate the opening and closing of the stomates. When the guard cells are turgid, the stomate is open. As the guard cells lose water their turgor decreases and as a result the stomate closes. The functions of the stomates are threefold: 1. regulating the loss of water vapor into the outside air; 2. admitting carbon dioxide used in making carbohydrates and releasing free oxygen, the by-product of food manufac-



25-3 This chloroplast of a corn cell is shown magnified about 15,000 times by the electron microscope. (A. E. Vatter)

ture; 3. admitting oxygen when needed for respiration, and giving off of the carbon dioxide formed by respiration. Stomates would not be of much use if it were not for the many air spaces into which they open. By means of these spaces, all parts of the leaf have access to air for food-making, respiration, and other processes.

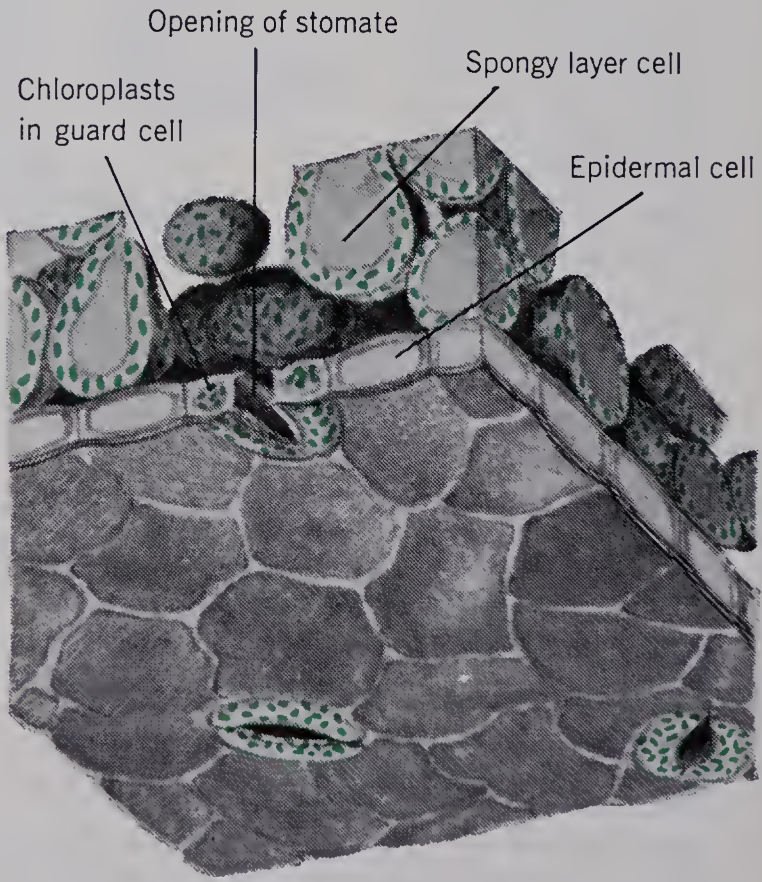
The number of stomates varies from 60,000 to 450,000 per square inch. There are usually many more on the lower surface than on the upper. Leaves that float on water, however, have all their stomates on the upper surface. In vertical leaves they are about evenly distributed.

Leaf adaptations to light and water conditions. No factor of the physical environment has as great an influence on the leaf as light. As a source of energy necessary for food manufacture, light has a direct bearing on the nutrition of the entire plant. The supply of food depends on the extent to which a plant displays its leaves to light.

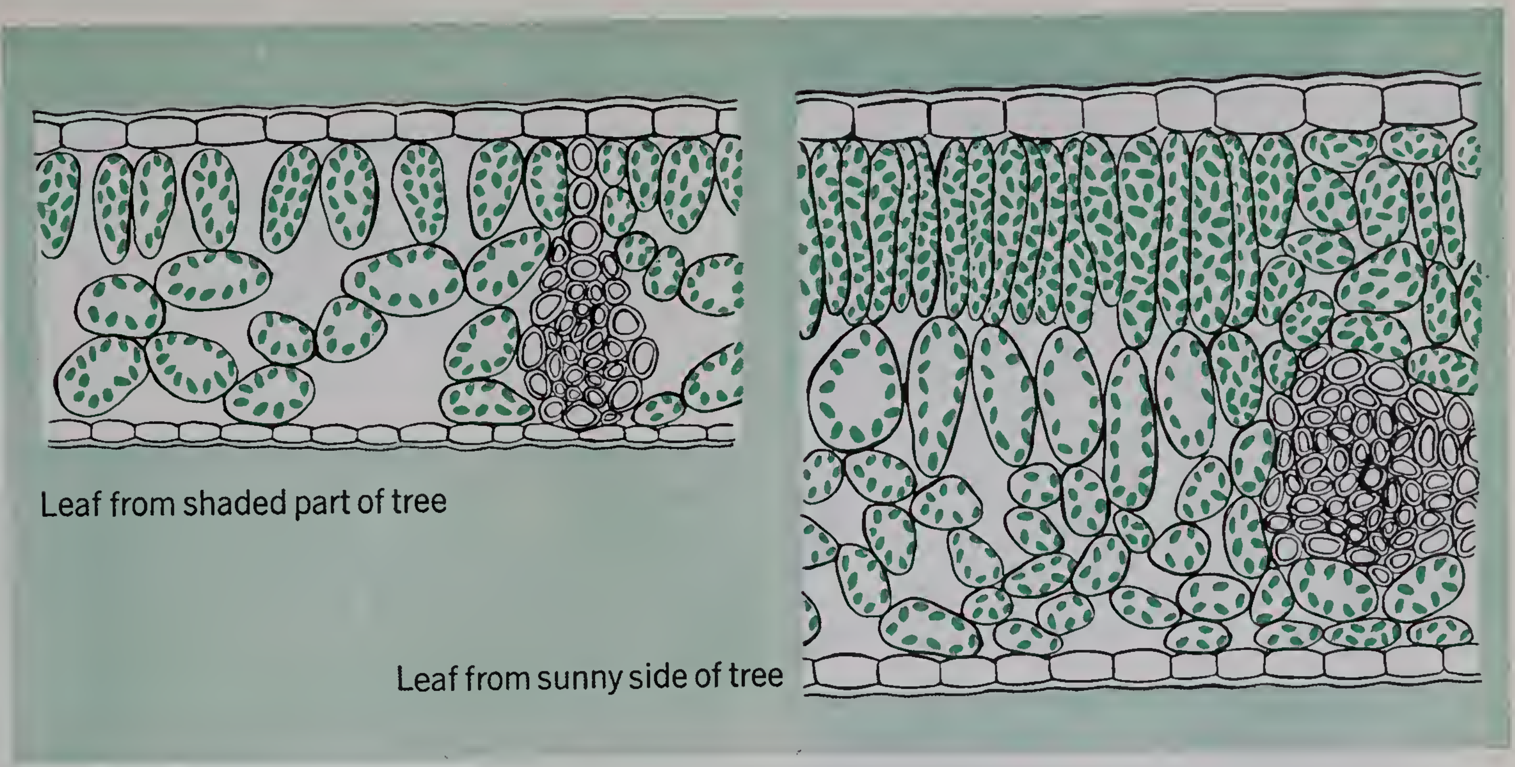
Leaves are arranged on the stem in a way that will expose each to the most light. Each leaf is produced at a different angle on the stem. For example, two leaves arranged in a north-south direction will alternate with leaves arranged in an east-west direction. Thus, one leaf does not shade another growing from the node under it.

The general arrangement of leaves on the stem tends to put each in the best position to get light. Any rigid placing of leaves would not be very effective among plants that must compete with one another for light. Individual leaves can adjust the position of their blades by a bending of the petiole. As you would expect, this bending is a phototropic response like that of stem growth toward light.

Light further influences leaf growth in the make-up of the internal tissues. Leaves exposed to bright light usually develop one or more layers of compact palisade cells on the upper side. They also have many cells in the spongy layer. Shaded leaves have fewer layers of palisade cells, or none at all, and they have fewer spongy cells than



25-4 Numerous stomates occur on the lower epidermis of most leaves. What is the function of these stomates?



25-5 Compare these drawings of leaves taken from a plant growing in the shade and a plant growing in direct sunlight.

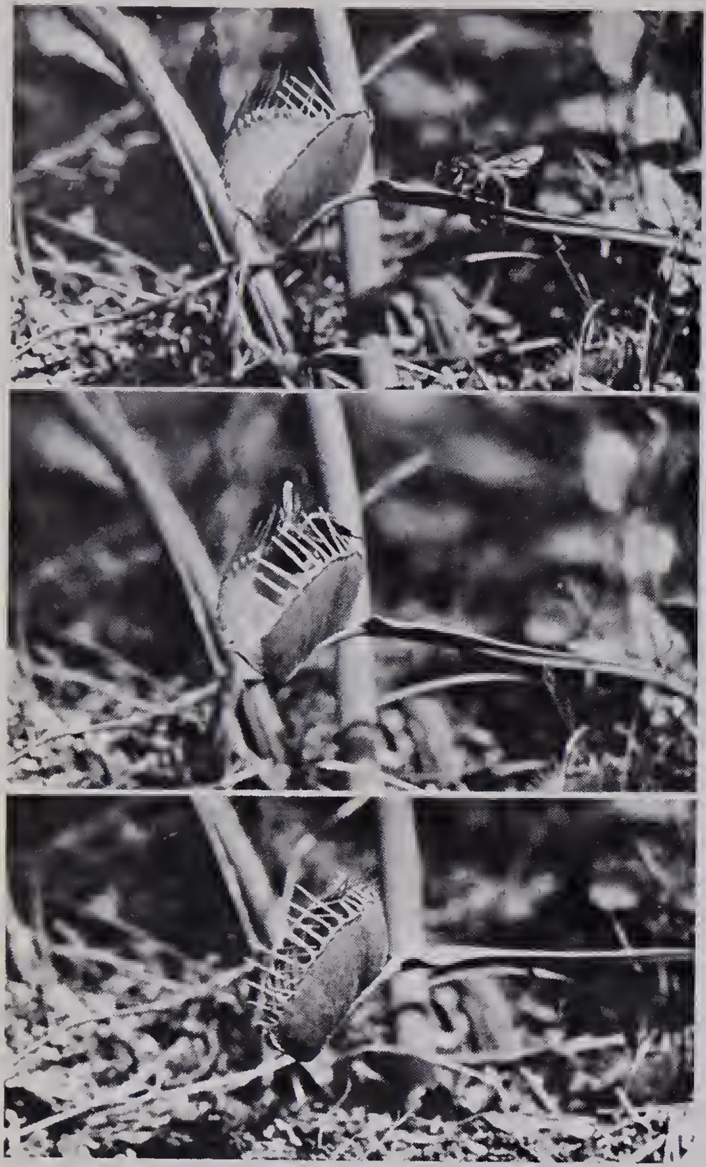
leaves growing in bright light (Fig. 22–5).

The critical relationship between a leaf and light is shown in the influence of light on leaf area. In places of reduced light, as for example the inside or lower branches of a tree, leaves tend to be larger than those at the tips of branches or at the top where abundant light strikes them. Similarly, the leaves of various species vary according to the type of environment. The trees of the dense tropical rain forests have leaves with large blades for maximum exposure to light. The leaf blades in our more open temperate forests, on the other hand, are much smaller.

Like light, moisture affects the size and growth of leaves. In regions of heavy rainfall and moist atmospheric conditions, leaves are often larger than those of the same species in a drier climate. As rainfall decreases and air becomes drier, leaves tend to become smaller. In extremely dry places plants have hardly any leaves at all, as in the cactus, in which leaves are reduced to mere spines.

Other leaf modifications. Leaves are frequently reduced to mere tendrils, or they may develop as thorns. Some plants, such as the sedums (*seed*-umz), have leaves thickened with stored food and water. Leaf cuttings of sedum or begonia will reproduce the plant when they are put in moist sand. Perhaps the most curious adaptation of leaves is found in the Venus's-flytrap, the sundew, and the pitcher plant, which have leaves modified in various ways for capturing insects (Fig. 25–6). The insects are then digested by special enzymes secreted by the plant. Although the insectivorous plants are autotrophs and can synthesize their own carbohydrates, they usually live in areas scarce in nitrogen. Thus, the insect diet supplies the missing nitrogen.

Leaf coloration. During the late spring and summer leaves are green because chlorophyll is present in the chloroplasts. In addition to chlorophyll, the chloroplasts also contain the yellow ***xanthophyll*** and orange ***carotene.*** Chlorophyll, however, masks these two other pigments.



25-6 These photographs show the Venus's-flytrap leaf in the act of capturing an insect. The bee in the top photograph is quite unsuspecting as he hopes for nectar in approaching the trap. In the middle picture he is trapped and the leaf is closing. At the bottom he is completely engulfed and the plant then will secrete special enzymes which digest the insect. (United Press International)

With the coming of fall, the temperature is apt to drop below the point necessary for chlorophyll formation. Light destroys the remaining chlorophyll, and the previously hidden yellow and orange pigments become obviously apparent.

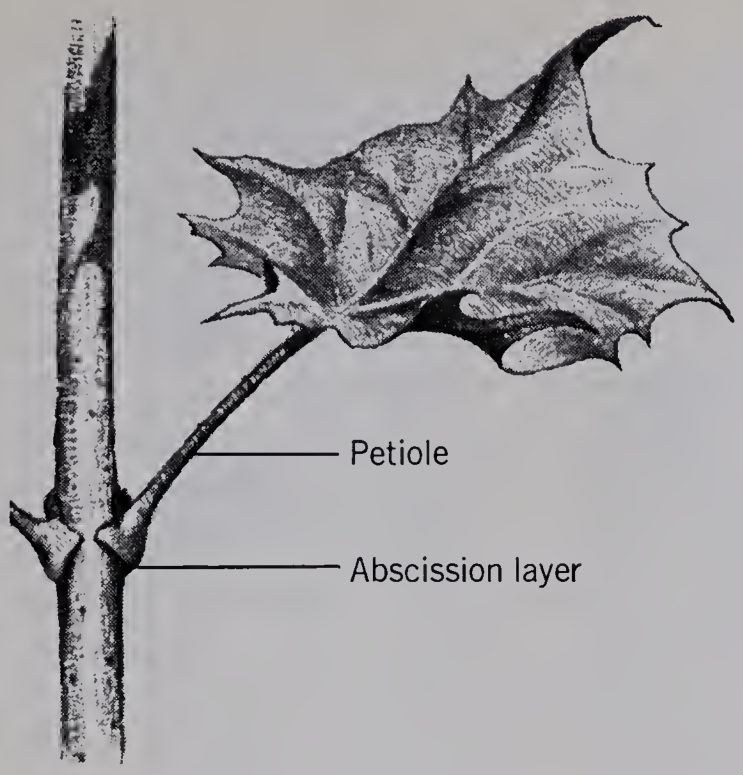
Cool weather also promotes the formation of the red pigment ***anthocyanin*** (ant-tho-*sy*-a-nin) in many leaves. This red pigment does not form in the chloroplasts but in the cell sap in vacuoles of the leaf cells. It is formed from food materials. This pigment accounts for the red appearance of leaves of many woody plants during the cool spring and fall seasons.

Brown coloration results from the death of leaf tissues and the production of tannic acid inside the leaf.

The falling of leaves from their branches. The natural fall of leaves is caused by an ***abscission*** (ab-*sizh*-uhn) ***layer*** consisting of a layer of cells across the base of the petiole (Fig. 25–7). Soon after the layer forms, its walls separate from the stem and leave the petiole attached only by its fibrovascular bundles. In some trees the slightest jarring or gust of wind will cause the leaf to drop. A thin layer of cork cells seals the scar where the leaf was attached to the stem. The leaves of some trees stay on during the winter and do not drop until the coming of spring.

While evergreen trees do not shed all their leaves at any one time, new leaves usually appear during the spring and replace those of the previous season.

The leaf and photosynthesis. Although other plant cells contain chlorophyll, the principal photosynthetic cells of the green plant are the mesophyll cells. These cells are truly little factories of activity utilizing the water and dissolved substances brought from the root up the stem to the veins. The carbon dioxide necessary for the process enters through the stomates, and excess oxygen passes out through the same pores. The resulting carbohydrates may be stored in the palisade and spongy layers, as well as in the guard cells, or they may be used in respiration or in the synthesis of other carbohydrates, fats and oils, or proteins in other parts of the plant.



25-7 During the usually cool weather of autumn, the cell walls of the abscission layer across the base of the petiole separate from the stem so that the slightest jarring will cause the leaf to drop.

Since the stomates admit carbon dioxide for photosynthesis, the regulation of their opening and closing is very important to the plant. As we said earlier, the water content of the guard cells determines whether the stomate is open or closed. What in turn determines the water content of the guard cells? The answer lies in an interesting chemical regulation which allows for the varying needs of the plant. An important factor in this chemical regulation is the fact that carbon dioxide combines with water to form carbonic acid, and that less starch is converted to sugar in an acid environment. Now, think back to the fact that stomates contain chloroplasts, so that photosynthesis takes place in them as it does in the mesophyll cells. Carbon dioxide is, of course, used in making sugar in the process. As photosynthesis occurs in the guard cells, then, carbon dioxide is used up and the acid content of the guard cells decreases. As a result of this more starch is converted to sugar. How does a higher sugar concentration affect the water content of the cell? Remember osmosis — if the concentration of sugar molecules in the guard cells increases, there must be a decrease in the concentration of water molecules relative to the surrounding cells. You can predict what happens: water molecules will diffuse into the guard cells from the cells around them. The resulting turgidity will in turn open the stomates and more carbon dioxide will be admitted for further photosynthesis. Thus carbon dioxide is acting as a chemical regulator which controls its own concentration. This control in response to varying needs is another example of homeostatic regulation in living things: the organism maintains a balanced, steady state in the face of changing conditions.

If this series of events opens the stomates in the morning, you would expect that the reverse happens in the evening, when the sun goes down. This is exactly what happens. In reduced light, photosynthesis stops and the carbon dioxide content of the guard cells increases. This in turn increases the formation of carbonic acid, so that less sugar is formed from starch. This, in turn, reduces water absorption by the guard cells, causing decrease in turgor and change in the shape of the guard cells, resulting in closing of the stomates.

Respiration in green plants. Photosynthesis occurs only during the sunny hours, but respiration occurs night and day. Respiration in the seed plant is like that of other organisms. Glucose is the principal fuel from which energy is released, and glucose molecules are oxidized by the removal of hydrogen, as we explained in Chapter 7. Oxygen is the ultimate hydrogen acceptor and combines with it to form water, a product of respiration. Carbon dioxide is released as the carbon skeleton of the glucose molecule is broken down.

We may not be aware of plant respiration because it does not involve breathing. However, the process is just as important to the plant as to the animal, even though the rate is much lower.

Plants require energy for all of their internal processes. Some energy is used in the streaming of cell protoplasm. In addition, energy is required in the synthesis of carbohydrates other than glucose, fats, proteins, and nucleic acids. Growth of the plant requires a constant supply of energy.

Photosynthesis and respiration compared. The relationship between photosynthesis and respiration is interesting. They would almost appear to be opposite chemical reactions. However, this is not the case. The enzymes and chemical reactions involved in the two processes are different. We can say, though, that photosynthesis and respiration are complimentary processes. The requirements of one process are products of the other. This is an important aspect of the biochemical balance maintained in a biological society.

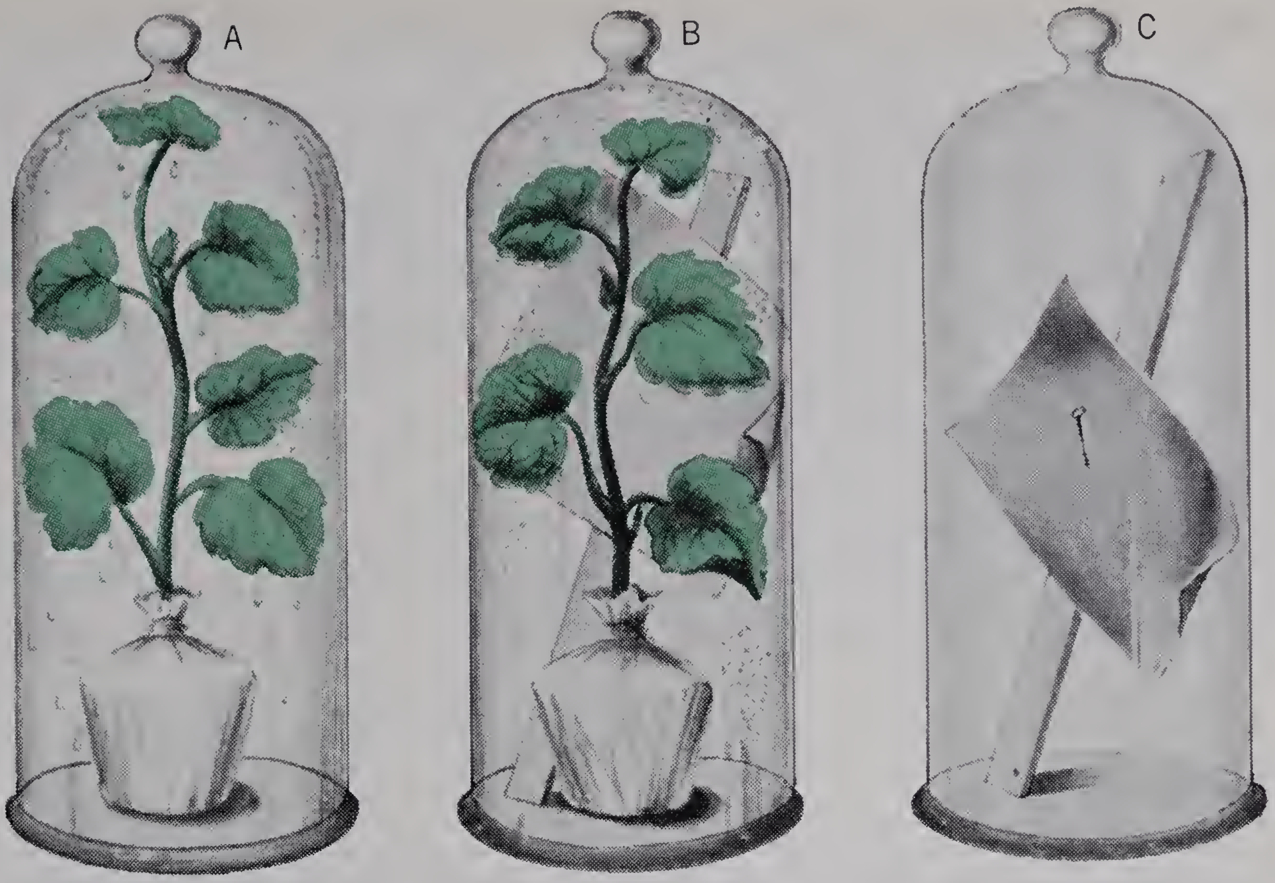
The complementary relationship of photosynthesis and respiration becomes more apparent when you compare the matter and energy changes involved in the two processes, as in the table below.

As you compare the two processes, notice that matter flows in a cycle. That is, matter may be used over and over. This cycle also involves an endless change of inorganic molecules to organic molecules, followed by a return to the inorganic state. However, while matter cycles, energy does not. Light energy is used in photosynthesis, while heat and useful energy are released in respiration. Energy to support photosynthesis must be received as light. For this reason life will always be dependent on the sun for energy.

Perhaps you have wondered if photosynthesis and respiration balance each other in a plant. They may if the plant is in very reduced light, which slows down the rate of photosynthesis greatly. However, in bright sunshine, photosynthesis occurs at a rate ten times that of respiration, or more. At night, of course, photosynthesis ceases while respiration continues. However, the total photosynthesis carried on by a plant far exceeds the total respiration. This places the green plants of the earth in the position of food and oxygen producers for

COMPARISON OF PHOTOSYNTHESIS AND RESPIRATION

Photosynthesis	*Respiration*
Food accumulated	Food broken down (oxidized)
Energy from sun stored in glucose	Energy of glucose released by oxidation
Carbon dioxide taken in	Carbon dioxide given off
Oxygen given off	Oxygen taken in
Produces PGAL	Produces CO_2 and H_2O
Goes on only in light	Goes on day and night
Only in presence of chlorophyll	In all living cells



25-8 A: water vapor from the plant is condensing on the sides of the bell jar. B: the water vapor turns the indicator (cobalt paper) pink in 15 minutes. C: the blue color of the cobalt paper in this control jar does not change.

the totally dependent heterotrophic plants and animals.

Storage and translocation of foods. During a bright warm day photosynthesis forms PGAL and glucose in leaf cells much more rapidly than the plant can remove it to other parts. As a result, most leaves convert the sugar to starch either immediately or soon after it is formed. As the day's food manufacture progresses, starch grains become more and more abundant. About the middle of the afternoon, the starch content reaches its peak.

In the evening light is reduced and photosynthesis slows down. It stops almost entirely at night but may continue slightly on a clear, bright moonlit night. Through the night the stored starch in the cells of the leaf is converted to sugar, which dissolves in water. The *translocation,* or movement of the sugar solution through the veins into the stem, continues all night. At daybreak, when photosynthesis begins again, the food-making cells are cleared of stored food and are ready for the product of a new day's activity.

Transpiration in plants. During the growing season a plant conducts a continuous stream of water up through its roots and stem into the leaves. This flow of water carries dissolved minerals that are used in the manufacture of proteins, chlorophyll, and other products. Some water is used for maintaining cell turgor and some for photosynthesis. With all of its uses, however, much more water is absorbed than the plant can use. The excess escapes through the leaves (Fig. 25–8).

During the process known as *transpiration,* water passes from the air spaces in the spongy areas through the stomates and into the air as a vapor. While transpiration primarily involves the leaves, other plant parts may be involved.

Transpiration is more than evaporation. We see this in the different rates at which it occurs under different conditions. The rate of transpiration is controlled to a major extent by the opening of the stomates. Remember that this opening is controlled by the water content of the guard cells. When the guard cells are full of water, the stomate is open. When the guard cells lose water, they change shape and the stomate closes, thus reducing water loss. Closed stomates will greatly slow up transpiration but will not stop it.

That leaves cannot entirely stop transpiration, even with their stomates closed, is clearly shown in the wilting that frequently occurs on hot days. Such wilting ceases in the evening when the atmosphere cools and absorption makes up the water deficiency. Transpiration is especially dangerous to plants after transplanting. The removal of some of their leaves reduces the evaporation of water vapor from the leaves.

IN CONCLUSION

The leaf is the food factory for the plant, and indeed for most animal life. Through leaves, plants respire and carry on photosynthesis, the latter producing oxygen and carbohydrates.

At the end of a season of activity, many plants shed their leaves. New, active leaves take up their work the following growing season. Even the evergreen plants lose their old leaves and grow new ones at regular intervals. Thus, the food factories of seed plants remain young and active.

In the following chapter, we shall consider reproduction in flowering plants.

BIOLOGICALLY SPEAKING

abscission layer
blade
compound leaf
cuticle
epidermis
guard cell
leaflet
mesophyll
midrib
palisade parenchyma
palmate venation
parallel venation
petiole
pinnate venation
simple leaf
spongy parenchyma
stomate
translocation
transpiration
vein

QUESTIONS FOR REVIEW

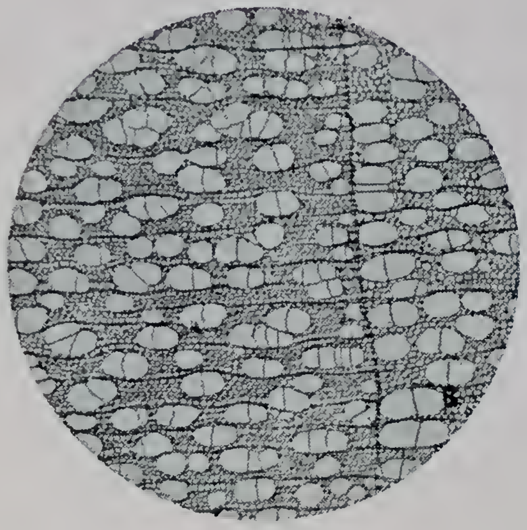
1. Why is it important that most leaf blades be thin and broad?
2. Name two important functions of leaf veins.
3. Distinguish between dicot and monocot leaves on the basis of their vein structure.
4. Name the tissues of a leaf from top to bottom.

5. Why are the numerous spaces in the spongy layer necessary for leaf activity?
6. Discuss the location, structure, and functions of the stomates of a leaf.
7. Discuss the relation of leaf size and numbers to atmospheric moisture.
8. Why do various pigments appear in leaves during the fall season?
9. How is sugar content related to the water content of guard cells? How is water content related to the opening and closing of the stomates?
10. Compare photosynthesis and respiration with regard to substances necessary for the processes, waste products formed, and energy changes that occur.
11. Explain how the rate of transpiration varies with the water content of a plant and conditions of the atmosphere.

APPLYING PRINCIPLES AND CONCEPTS

1. Most of the cells of a leaf have thin walls. Why is this important to the activities of a leaf?
2. In what way does carbon dioxide in the leaf act as a chemical regulator that controls its own concentration?
3. If photosynthesis did not occur at a much greater rate than does respiration in green plants, there would be no animal life on earth. Explain why this is true.
4. Do you agree or disagree with the belief that plants should be removed from a sick room at night? Explain your opinion.
5. A nurseryman planted a tree in full leaf during the month of June. After planting, he pruned back the branches and removed many of the leaves. Why did this give the tree a far better chance to survive?

CHAPTER 26



REPRODUCTION IN FLOWERING PLANTS

What is a flower? If you asked this question of a florist, you would get one kind of an answer. A forester would probably give you a different one, and a biologist would surely offer still another. Using the biologist's definition, we may define a flower as a very specialized structure of the angiosperms which is adapted for reproduction of the species. A flower is also a modified branch in which the leaves are very much altered to form the various parts. The flower bud, for instance, contains meristematic tissues as do the buds that produce leaves and branches. The flower is highly adapted for the type of reproduction this group of plants employs.

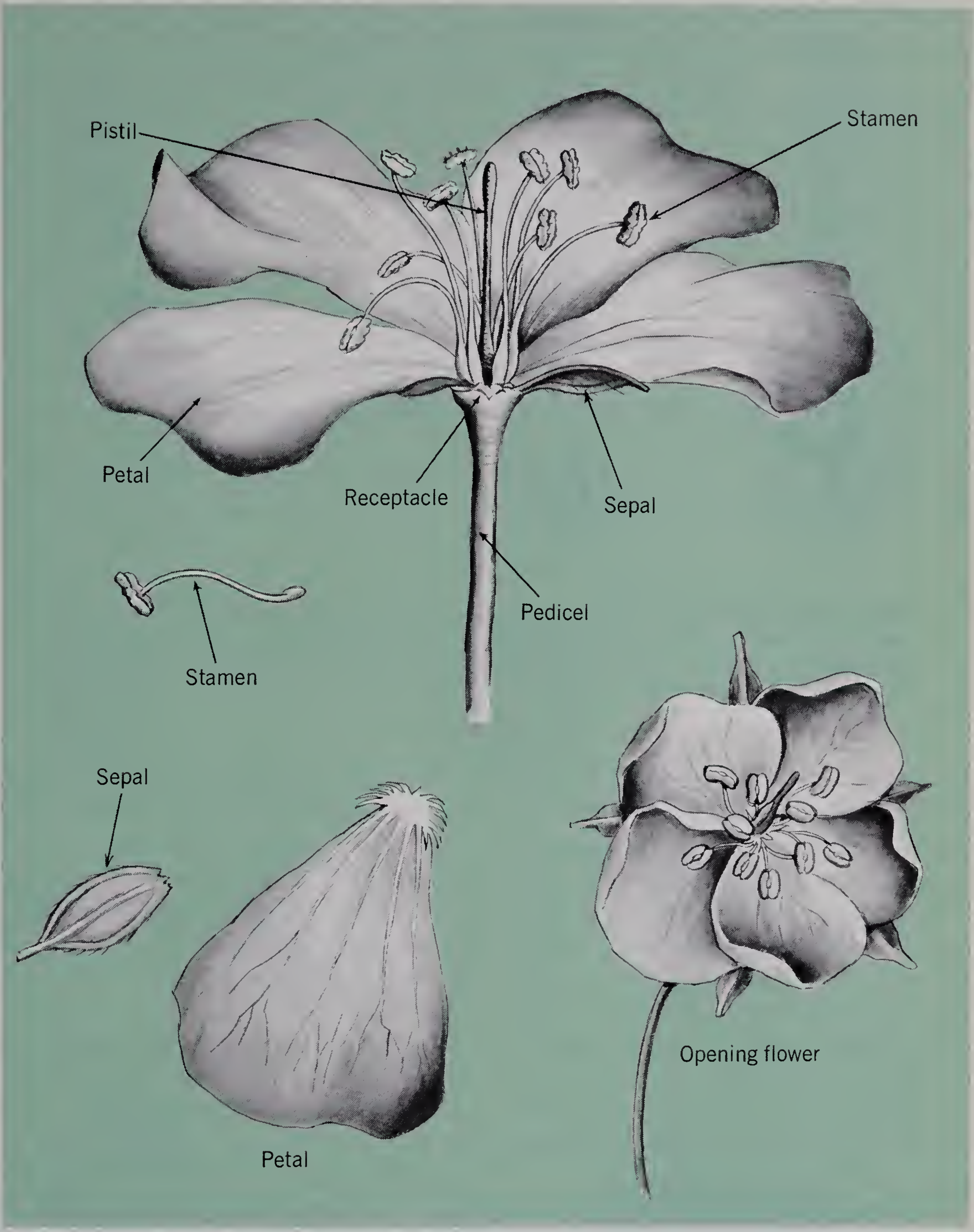
There is enormous variation among flowers. The lily, rose, orchid and tulip are handsome, colorful flowers. But the flowers of the oak, elm, maple, and birch are so inconspicuous as to be hardly recognizable as flowers at all. The flowers of grasses such as wheat, oats, rye, and our common lawn grasses are flowers in the botanical sense, but you would scarcely think of them as such.

Floral parts. A typical flower, such as the geranium, apple blossom, snapdragon, sweet pea, or petunia, has four sets of parts (Fig. 26–1). These parts grow from a special flower stalk, or ***pedicel*** (*ped*-i-sel), the end or tip of which is the ***receptacle.*** The outer ring of floral parts consists of several green leaflike structures called ***sepals*** (*seep*-alz). Together, the sepals form the ***calyx*** (*kay*-liks). The sepals cover and protect the rest of the flower in the bud stage. They also help to support the other parts when the bud opens.

Inside the calyx is the ***corolla*** (ko-*rahl*-a), which usually consists of one or more rows of ***petals.*** These are often but not always brightly colored. The calyx and corolla frequently attract insects, as we shall see later. They may also help to protect the inner parts. In certain flowers, like the tulip, both the calyx and corolla are the same color. It is possible to miss the fact that both parts are present.

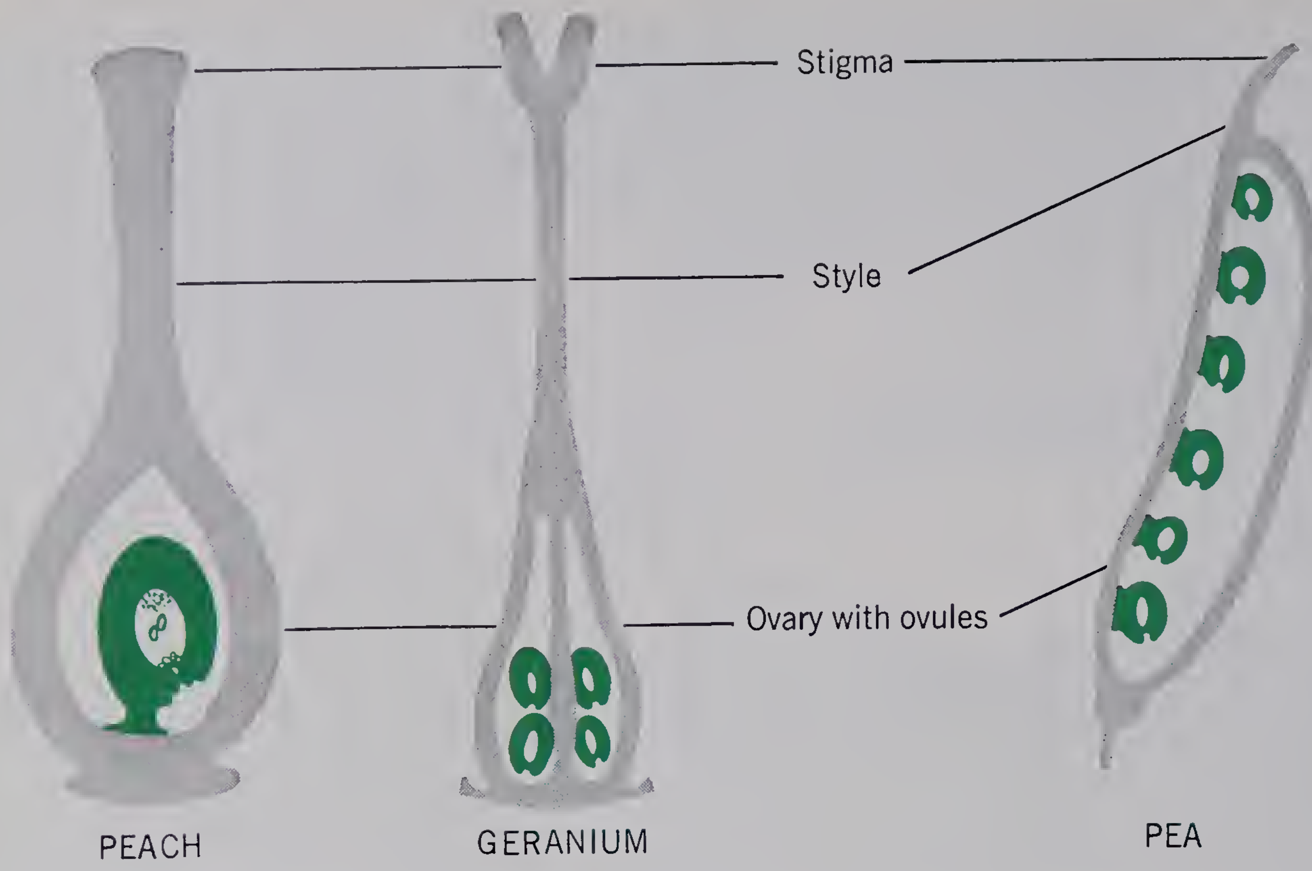
Two kinds of essential parts are concerned directly with reproduction: the stamens and the pistil, located in the center of the flower. Each ***stamen*** (*stay*-men) consists of a slender stalk, or ***filament,*** supporting a knoblike sac called an ***anther.*** The anther produces various colored grains called ***pollen,*** which are essential in reproduction.

The ***pistil*** consists of a sticky top, called a ***stigma,*** a slender stalk, or ***style,*** which supports the stigma, and a swollen base, or ***ovary,*** which is joined to


Pistil
Stamen
Petal
Receptacle
Sepal
Pedicel
Stamen
Sepal
Opening flower
Petal

26-1 This is a complete flower, having all four parts.

the receptacle of the flower stalk. Inside the ovary are the *ovules*, which will later become seeds. The ovules are attached to the ovary either at its base, or along the side walls, or to a special stalk running lengthwise from the base of the ovary to the base of the style. Ovules may number from one to several hundred, depending on the kind of flower.



26-2 Various patterns of attachment of ovules to ovary. In the peach the one ovule is attached to the base of the ovary. In the geranium several ovules are attached to a special stalk in the center of the ovary. In the pea all ovules are attached to the side walls of the ovary.

Variation in flower structure. Flowers vary greatly not only in color, size, and shape, but also in their reproductive structures. Although many plants have both stamens and pistil on the same flower, some, such as the oaks, squash, and corn, have these structures on separate flowers on the same plant. Other species have flowers bearing pistils on one plant and flowers bearing stamens on another plant. Willows and cottonwoods are well-known and familiar examples of this type.

In studying stems and leaves you learned that dicots differ from monocots in the arrangement of their vascular tissue. As you might expect, they also differ in the structure of their flowers. Monocots, for example, usually have flower petals and essential parts in threes or multiples of threes, while dicots usually have them in fours or fives or their multiples.

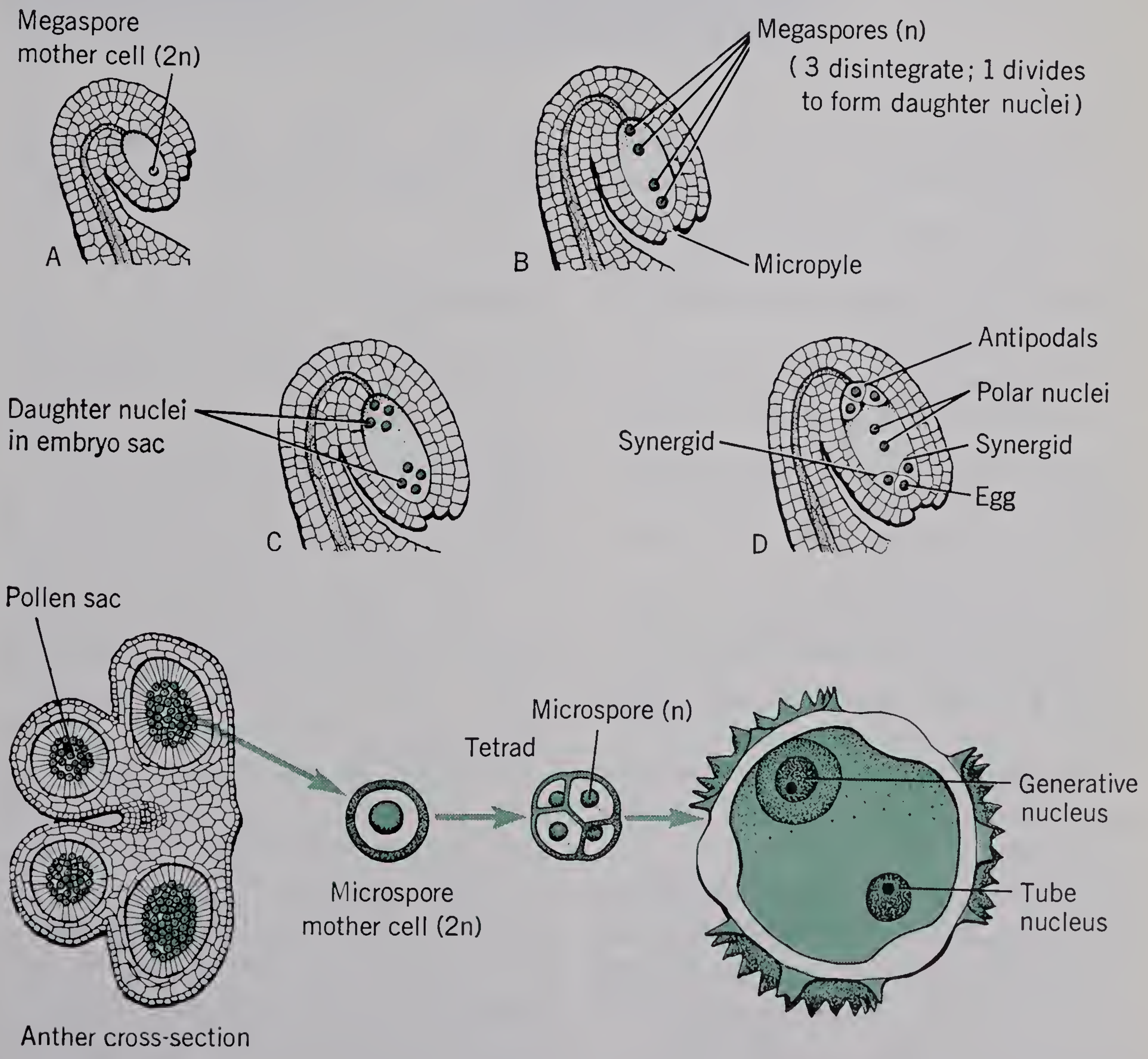
Some flowers are not single flowers in the biological sense but a whole cluster. The sunflower and daisy, for example, have dense clusters of reproductive flowers in the center, surrounded by so-called petals, which are really another type of flower and which usually attract insects.

The anther and pollen formation. If you examine a cross section of the developing anther of a large stamen, such as that of a lily or a tulip, you can see four chambers, or ***pollen sacs*** clearly (Fig. 26–3). During development of the flower, each pollen sac is filled with cells with large nuclei. These are known as ***microspore mother cells.*** Microspore mother cells contain pairs of chromosomes, or the diploid number ($2n$). As the anther grows, the nucleus of each microspore mother cell divides by meiosis forming first two daughter nuclei which divide again in the second part of meiosis, resulting in four. Cell walls form around each daughter cell, resulting in a four-celled tetrad. The cells are referred to as ***microspores.*** Microspores are thus haploid, because they always contain the *n* number of chromosomes.

Each microspore develops into a pollen grain. First the nucleus divides by mitosis forming two. One is designated as a ***tube nucleus*** and the other as a ***generative nucleus.*** The wall of the microspore thickens and becomes the protective covering of the pollen grain. At about this time the anther ripens and the wall between two adjacent pollen sacs disintegrates. The pollen sacs burst open, and the pollen is ready for distribution.

Development of the ovule. While pollen grains are forming in the anthers, changes are occurring in the ovary at the base of the pistil. For the sake of simplicity, we shall describe these changes in an ovary containing a single ovule, like the avocado pear. When there are several or many ovules in an ovary, the same general procedure takes place.

An ovule appears first as a tiny knob on the ovary wall. This swelling contains a single ***megaspore mother cell***


Megaspore mother cell (2n)
A
Megaspores (n)
(3 disintegrate; 1 divides to form daughter nuclei)
B
Micropyle
Daughter nuclei in embryo sac
C
Antipodals
Polar nuclei
Synergid
Synergid
Egg
D
Pollen sac
Microspore (n)
Tetrad
Generative nucleus
Tube nucleus
Microspore mother cell (2n)
Anther cross-section

26-3 In the drawings at the top, trace the steps in the formation of the ovule; then do the same in the bottom drawing for the formation of pollen.

(Fig. 26–3). This cell contains the diploid ($2n$) number of chromosomes. As the ovule grows, it is raised from the ovary wall by a short stalk through which nourishment is received. One or two protective layers form around the ovule and enclose it completely except for a tiny pore, or ***micropyle.*** The micropyle is usually on the lower side of the ovule.

The megaspore mother cell divides, followed by division of the daughter cells, resulting in a row of four ***megaspores.*** As in the formation of microspores, this double division is meiotic and reduces the chromosome content of the megaspores to the haploid number (n). Of the four megaspores produced in an ovule, one survives and the other three disintegrate. Usually the surviving megaspore is the one farthest from the micropyle. This remaining megaspore enlarges rapidly and forms an oval ***embryo sac*** in which further development occurs in the following steps (also see Fig. 26–3):

1. The megaspore nucleus divides and forms two daughter nuclei. Two additional mitotic divisions result in eight nuclei.
2. Four nuclei migrate to each end of the embryo sac.
3. One nucleus from each group of four, designated as a ***polar nucleus,*** migrates to the center of the embryo sac.
4. Each nucleus in the groups of three at either end of the embryo sac is enclosed by a thin membrane.
5. One of the cells nearest the micropyle enlarges and becomes the ***egg.*** The cells on either side of the egg and partially surrounding it are known as ***synergids*** (si-*ner*-jidz).
6. The three cells farthest from the micropyle are known as ***antipodals.***

The ovule is now ready for fertilization. However, only the egg and the polar nuclei will be involved in this process. Both the synergids and the antipodals are short-lived and have no apparent function. Before fertilization can occur, a pollen grain must be transferred to the stigma of the pistil by one of the various agents in pollination.

Pollination. We can define ***pollination*** as the transfer of pollen from the anther to the stigma. In some plants pollen is transferred from anther to stigma in the same flower or to the stigma of another flower on the same plant. We refer to this as ***self-pollination.*** If flowers on two separate plants are involved, the process is called ***cross-pollination.*** Cross-pollination requires an outside agent. The chief ones are insects, wind, and water. Curious adaptations of different kinds of flowers are frequently necessary to accomplish cross-pollination.

Adaptations for pollination. Chief among the insect pollinators are bees. But moths, butterflies, and certain kinds of flies visit flowers regularly and in so doing carry on cross-pollination. Insects come to the flower to obtain the sweet nectar secreted deep in the flower by special glands at the base of the petals.

Bees swallow nectar into a special honey stomach where it is mixed with saliva and converted into honey. When they return to the hive, the bees deposit the honey in six-sided cells of the comb and later use it as food. The plump hairy body of the bee makes it an ideal pollinator (Fig. 26–4). To reach the nectar glands at the base of the flower, the bee must rub its hairy body against the anthers. These are usually located near the opening of the flower. When the insect visits the next flower, some of the pollen is sure to rub

26-4 The bee is an ideal pollinator because of its plump hairy body. (Eisenbeiss from Photo Researchers)

against the sticky stigma of the pistil, while a new supply is brushed off the stamens.

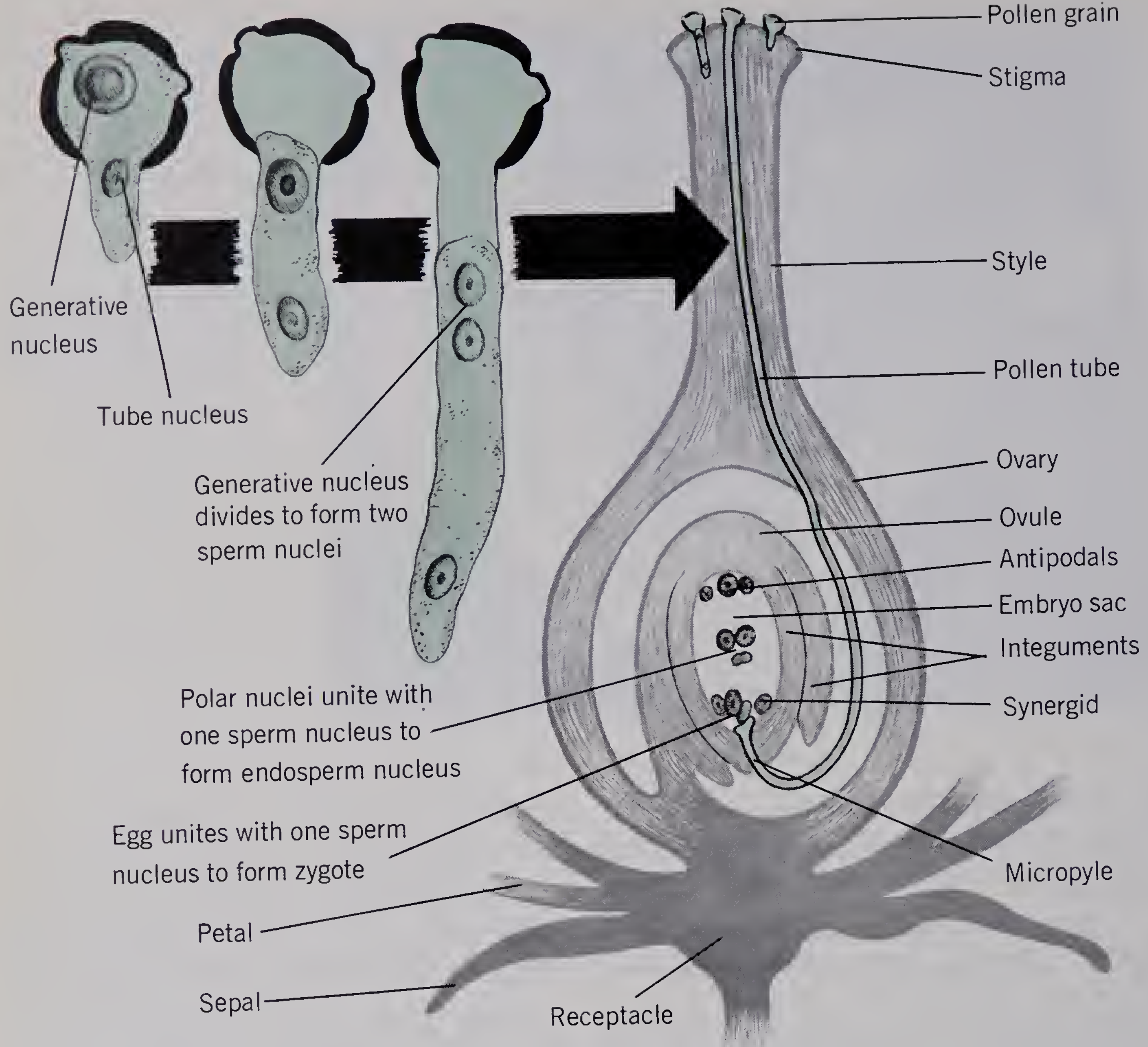
Brightly-colored petals and sweet odors aid insects in locating flowers. Nectar guides in some flowers may be brightly-colored stripes located on the petals.

We must include at least one bird in discussing agents of pollination. Tiny hummingbirds feed on nectar of certain flowers. Their long bills and equally long tongues reach down to the nectar glands while the bird hovers over the flower.

The flowers of wind-pollinated plants are much less striking than are those pollinated by insects. They are often borne in dense clusters near the ends of branches. As a rule petals are lacking and the flowers seldom have any nectar. Frequently the stamens are long and produce enormous quantities of pollen. The pistils are also long, and the stigmas are large and often sticky to catch pollen grains that are blown about by the wind. Cottonwood, willow, walnut, corn, oats, and other wind-pollinated plants literally fill the air with pollen when their stamens are ripe.

Growth of the pollen tube and fertilization. Once a pollen grain lodges on the sticky surface of the stigma of the pistil, it starts to form a ***pollen tube,*** which penetrates the stigma surface. As the tube lengthens, it grows through the soft tissue of the style and reaches the micropyle of the ovule. The tube nucleus of the pollen grain often disintegrates early. As the generative nucleus moves into the tube, it divides and forms two ***sperm nuclei,*** or male gametes. After passing through the micropyle, the pollen tube digests its way through the thin wall of the embryo sac. The tip of the tube ruptures and the two sperm are discharged into the embryo sac. Meanwhile the tube nucleus degenerates.

One sperm unites with the egg in fertilization. This produces the fertilized egg, or zygote. Both the egg and


Pollen grain
Stigma
Style
Pollen tube
Ovary
Ovule
Antipodals
Embryo sac
Integuments
Synergid
Micropyle
Generative nucleus
Tube nucleus
Generative nucleus divides to form two sperm nuclei
Polar nuclei unite with one sperm nucleus to form endosperm nucleus
Egg unites with one sperm nucleus to form zygote
Petal
Sepal
Receptacle

26-5 The drawings on the left show how the pollen tube and sperm nuclei develop from a pollen grain, while those on the right show in detail the ovule of a peach at the time of fertilization.

the sperm nuclei are haploid. Fertilization restores the diploid chromosome number ($2n$) in the zygote. Since the zygote will form the embryo plant by cell division, the cells of the plant will possess this diploid number until flowers are produced and reduction division occurs in the formation of microspores and megaspores.

The second sperm unites with the polar nuclei in the embryo sac and an *endosperm nucleus* is produced. Since both polar nuclei and the sperm contain the haploid chromosome number (n), the endosperm nucleus is a triploid ($3n$) structure. We refer to the union of the three nuclei to form the endosperm nucleus as triple fusion. These steps are summarized graphically in Fig. 26–5.

Immediately after fertilization auxins that were produced in the pollen grain and delivered to the ovule through the pollen tube stimulate rapid cell division and tissue growth within the ovule. The zygote undergoes an orderly development into the embryo plant. Meanwhile the endosperm nucleus gives rise to a mass of tissue which becomes the ***endosperm*** of the seed. This functions as a storage area to nourish the developing embryo plant. In some seeds the endosperm disappears after a short time. In others it remains as a part of the seed at maturity.

The gametophyte and the sporophyte in flowering plants. In our discussion of the algae, the fungi, and the ferns, we noted that some of these organisms have two distinct forms, the gametophyte and the sporophyte, in an alternation of generations. In the algae and the mosses, the gametophyte was the most conspicuous form. In the fern, the sporophyte has become the more conspicuous of the two generations. You may never have noticed the small, inconspicuous heart-shaped gametophyte of the fern. In the seed plants this trend has gone even further. The sporophyte is the plant that we see. The gametophyte has become completely dependent on the sporophyte, and is in fact microscopic. The male gametophyte in seed plants consists only of the pollen tube with its haploid sperm and tube nuclei. The female gametophyte consists of the embryo sac with its haploid egg, polar nuclei, antipodals, and synergids, found in the ovule. From this description of the gametophytes in seed plants, you can see that the vulnerable egg and sperm nuclei are well protected from drying within the tissues of the sporophyte. This evolutionary trend toward the more conspicuous sporophyte seems to parallel the development of 1. *vascular tissue;* 2. *roots;* 3. *epidermis;* and 4. *stomates*, starting with the ferns and arriving at the most efficient of the land plants, the angiosperms.

From flower to fruit and seed. Fertilization brings a sudden end to the work of the flower. As the sepals, petals, and stamens wither, a group of special hormones force the plant to pour its full energies into the development of the ovary and the ovules inside. After a few weeks the ovary and its contents ripen. In many plants, other nearby parts, such as the receptacle or the calyx, enlarge and become part of the fruit, so that we can define a fruit as a *ripened ovary, with or without associated parts.* A seed, on the other hand, is a matured ovule that is enclosed in the fruit.

Fruits, like the flowers from which they develop, vary greatly in structure. The way some of the common fruits are classified according to structure is given in the table on page 360. As you can see, a fruit need not be fleshy, like an apple, a peach, or an orange. A kernel of corn, a hickory nut, a bean pod with its beans, a sticky burr of burdock, and a cucumber or pumpkin are just as much fruits as the fleshy, juicy type. Thus the biological meaning of the word *fruit* is quite different from the meaning used in a grocery store.

The relation of fruits and seeds. One important fact about seeds: the new plant grows from a seed, not from a fruit. But the fruit is highly important because it encloses the seed and protects it from water loss, disease, insect attack, and other dangers while it is developing. Later the fruit serves as a device for distributing the seeds.

When seeds mature they must be carried from the parent plant by some means or other. If they fall to the ground close by, the parent plant will be surrounded by struggling seedlings and few of these will have much chance of survival. Nature avoids this waste by attempting to scatter seeds as far as possible from the parent plant, a process

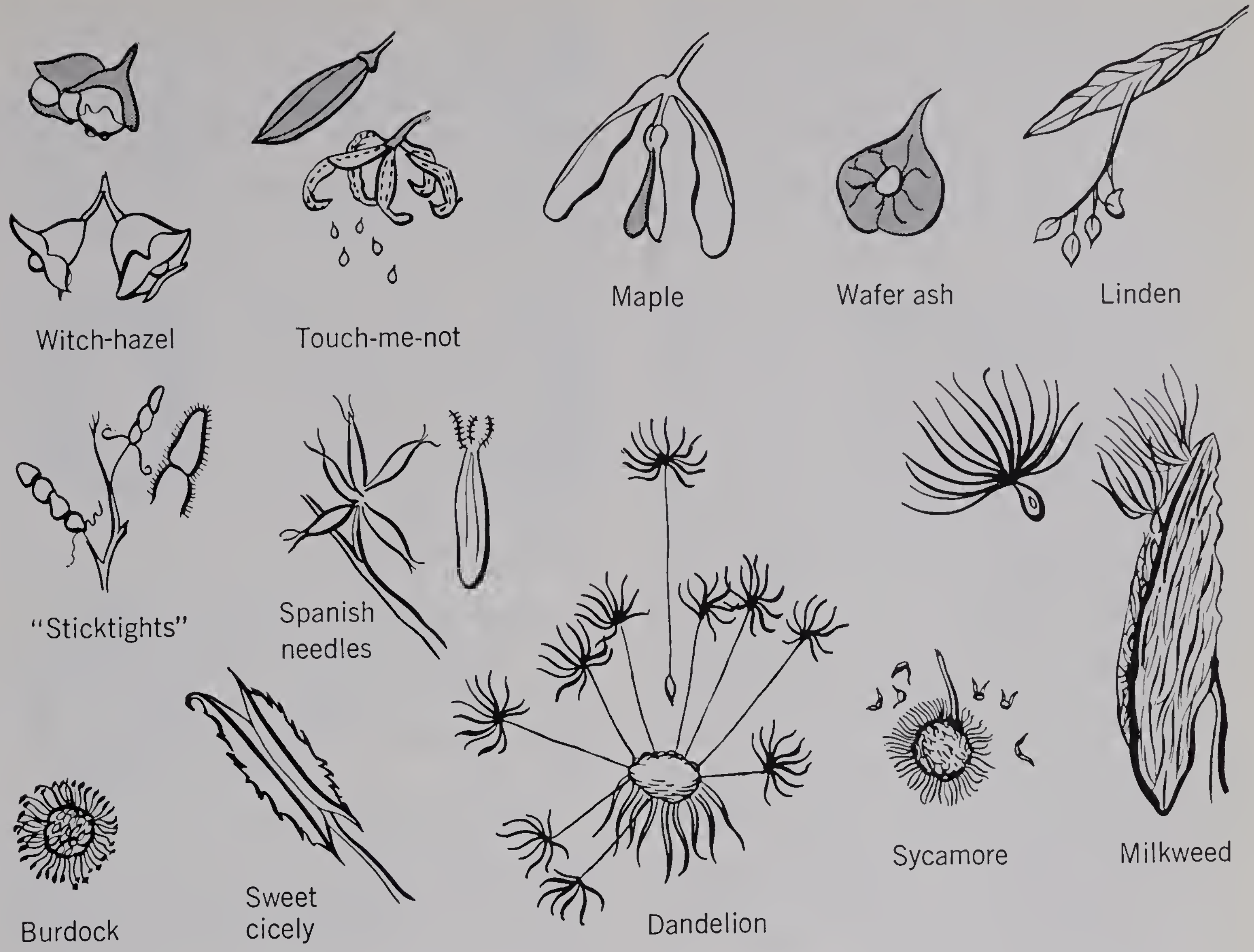
CLASSIFICATION OF FRUITS

Type	*Structure*	*Examples*
	Fleshy Fruits	
Pome	Outer fleshy layer developed from calyx and receptacle; ovary forms a papery core containing seeds	Apple, quince, pear
Drupe	Ripened ovary becomes two-layered — outer layer fleshy, inner layer hard, forming stone or pit, enclosing one or more seeds	Plum, cherry, peach, olive
Berry	Entire ovary fleshy and often juicy; thin-skinned and containing numerous seeds	Tomato, grape, gooseberry
Modified berry	Like berry, but with tough covering	Orange, lemon, cucumber
Aggregate fruit	Compound fruit composed of many tiny drupes clustered on single receptacle	Raspberry, blackberry
Accessory fruit	Small and hard; scattered over surface of receptacle; edible portion formed from enlarged receptacle	Strawberry
Multiple fruit	Compound fruit formed from several flowers in a cluster	Mulberry, pineapple
	Dry Fruits (dehiscent)	
Pod	Ovary wall thin, fruit single-chambered, containing many seeds; splits along one or two lines when ripe	Bean, pea, milkweed
Capsule	Ovary containing several chambers and many seeds; splits open when mature	Poppy, iris, cotton, lily
	Dry Fruits (indehiscent)	
Nut	Hard ovary wall enclosing a single seed	Hickory nut, acorn, pecan
Grain	Thin ovary wall fastened firmly to single seed	Corn, wheat, oats
Achene	Similar to grain, but with ovary wall separating from seed	Sunflower, dandelion
Winged fruit or samara	Similar to achene but with prominent wing attached to ovary wall	Maple, ash, elm

we refer to as ***seed dispersal*** (Fig. 26–6).

Sometimes only the seed is transported, but often the entire fruit is carried to a new location. In some plants seed dispersal is a mechanical process, while in others an outside agent, such as the wind, water, a bird, or some other animal, is involved. We shall consider some of the methods by which fruits and seeds travel from the parent plant.

Pod fruits, like the bean and pea, often twist as they ripen as a result of changes in the amount of moisture in the air. This causes a strain on the pod so that it bursts open suddenly and with enough force to throw the seeds some distance from the parent plant. Another interesting example of *me-*



26-6 Describe the various ways in which these fruits and seeds are adapted for dispersal.

chanical dispersal of seeds is the fruit of the garden balsam, or touch-me-not. When the fruits of this plant are ripe, they open upon the slightest touch and curl upward violently with the result that the seeds may be thrown several feet. Capsules, like the poppy, do not split open along the sides, but holes form around the top as the ovaries ripen. They resemble salt shakers and as the fruit sways back and forth on a long and flexible stem in the breeze, seeds sift out.

The delicious flesh of the apple, grape, or cherry is a sort of biological bribe. Birds and other animals feed on the fruits and scatter the seeds. Often the seeds pass through the digestive tract of an animal unharmed because their cellulose covers cannot be digested, and then they are deposited far from the parent plant.

Animals aid in fruit and seed dispersal in another way. Many plants produce fruits with stickers or spines that cling to the fur of animals. You might have aided plants in seed dispersal if you ever sat down after a hike in the fall to pick off the beggar's lice, sticktights, and burdocks that were stuck to your clothes.

Water is the agent of dispersal for many seeds. The coconut palm, for instance, often lives close to the shore and drops its fruit into the water. The thick, stringy husk of the coconut is waterproof. When the seed germinates, a sprout pushes through one of the three "eyes" on the end of the hard covering. Grasslike plants, known as sedges, are among some other plants that may drop their fruits into the water. They, like the coconut, are generally found along the shores of oceans or the banks of rivers and streams where their seeds may have found a foothold on the land.

The *wind* is the agent of dispersal for many fruits and seeds. When the milkweed pod splits open, the wind empties the pod of its seeds and each, equipped with a miniature parachute, is carried to a new location (Fig. 26–6). You have probably blown the fluff off a dandelion or thistle head. The fruits of these plants often travel long distances on their tiny tufts. In the spring the cottonwood tree fills the air as spring breezes empty its catkins of cottony tufted seeds. The winged seeds of maple, ash, elm, and pine whirl in the air like tiny propellers and are scattered to a considerable distance from the place where they develop.

What is a seed? We defined a seed as a matured ovule and as the final product of plant reproduction. A seed contains a tiny living plant, the ***embryo,*** stored food, and the seed coats. The stored food nourishes the young plant from the time it starts to grow until it can produce its own food by photosynthesis. The regions in which food is stored may vary with different seeds. In some seeds food is stored in thick "seed leaves," the ***cotyledons.***

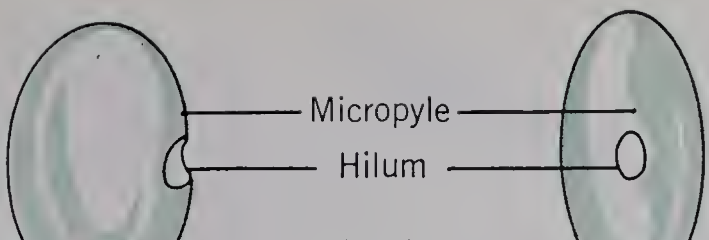
You may have seen thick cotyledons on the stems of such young plants as the green bean or lima bean shortly after they have pushed through the garden soil. They are located below the foliage leaves and last for only a few days before they wither and fall off. The number of cotyledons in the seed serves as the basis for the classification of the angiosperms. Monocot plants have only one cotyledon in their seeds, while dicot plants have two.

Not all seeds have the same kind of food stored in the cotyledons. A grain of corn, for example, has its starch and protein stored in the endosperm, while the cotyledon contains oils and proteins. The endosperm, filling much of the corn seed, develops from the endosperm nucleus after it unites with one of the two sperm during fertilization. On the other hand the major part of the bean seed is made up of the two cotyledons, which store a large amount of starch as well as proteins and oil. Some seeds have a large endosperm, while others have a very small endosperm or none at all. One of the latter is the bean.

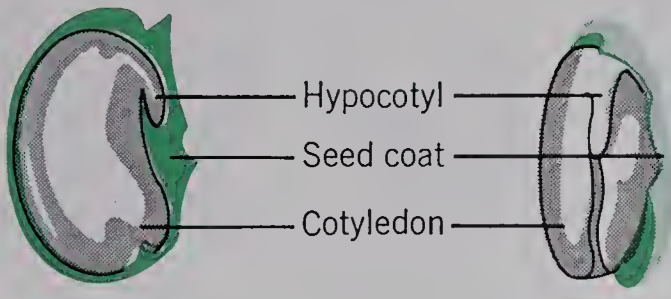
Seed coats cover the seed and protect it from drying out and from other dangers before it germinates. Usually there are two seed coats, but some seeds have only one. The outer coat is usually tough and thick. The inner coat is much thinner.

Structure of a bean. The bean seed is usually kidney-shaped (Fig. 26–7). The outer seed coat, the ***testa,*** is smooth and may be white, brown, red, or other colors, depending on the species. An oval scar on the concave side, the ***hilum*** (*hy*-lum), marks the place where the bean was attached to the wall of the pod. Near one end of the point of attachment is the tiny pore, the micropyle. The pollen tube grew through this tiny opening in the wall of the ovule just before fertilization. The inner seed coat of a bean is a thin, white tissue which is difficult to separate from the testa. Both of these coats have developed from the wall of the ovule.

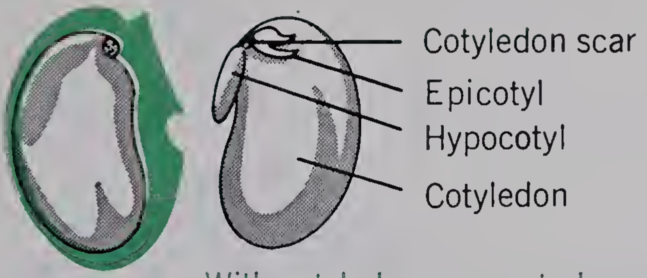
If you soak a dried bean and remove the seed coats, the cotyledons will separate easily. The cotyledons fill the


Micropyle
Hilum

Exterior


Hypocotyl
Seed coat
Cotyledon

With seed coat opened


Cotyledon scar
Epicotyl
Hypocotyl
Cotyledon

With cotyledons separated

26-7 This shows the external and internal structures of the bean seed.

space within the seed coats, and are thick and fleshy and not at all leaflike.

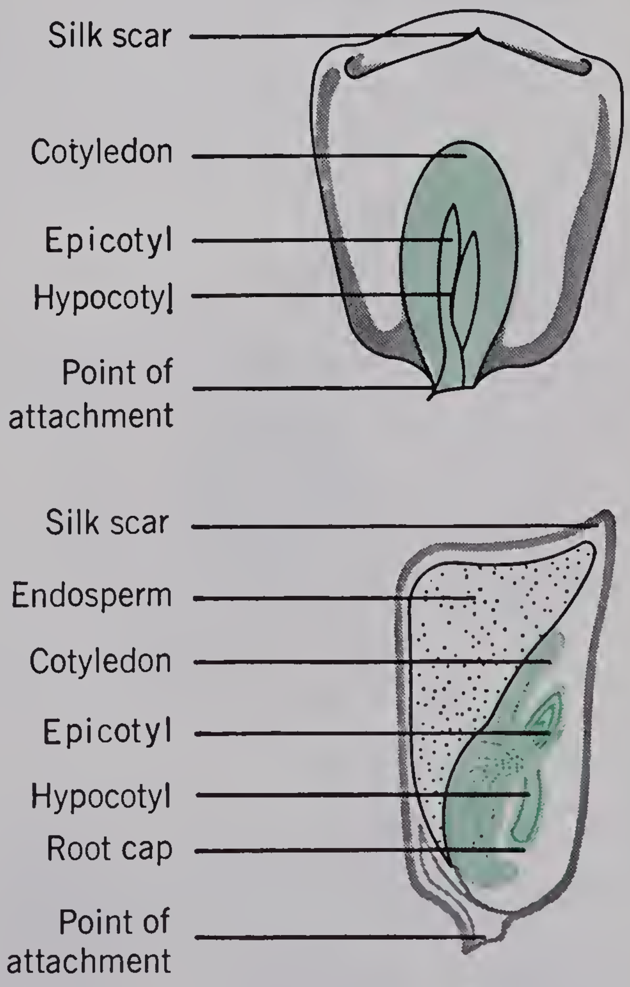
Lying between the cotyledons are the other parts of the embryo plant. A fingerlike projection, the ***hypocotyl,*** fits into a protective pocket of the seed coats. It is that part of the embryo axis between the cotyledons and the ***radicle*** (embryonic root).

The ***epicotyl*** joins the upper end of the hypocotyl. It consists of two tiny leaves, folded over each other, and between them lies the minute bud that will later form the plant's terminal bud as the epicotyl develops into the shoot. The location of the cotyledons is important to the seedling. Both the hypocotyl and the epicotyl will grow rapidly when the seed germinates and the cotyledons supply nourishment to both.

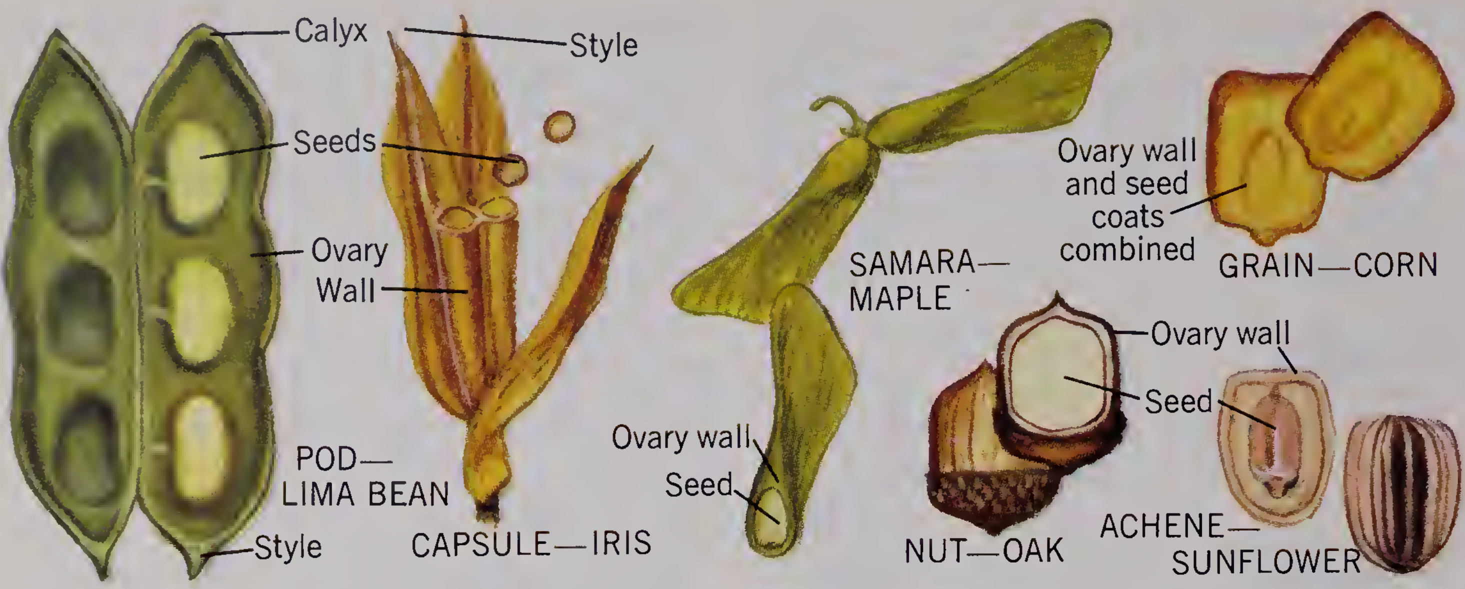
Structure of the corn kernel. Each corn grain is really a complete fruit, and therefore it corresponds to the bean pod and its contents rather than to the individual bean seed. However, there is only one seed in each grain and it completely fills the fruit, the outer coat of the kernel having been formed from the flower's ovary wall. A very thin inner seed coat is fastened tightly to the outer one and is only one cell layer thick. It developed from the wall of the ovule.

The micropyle is covered by the fruit coat, but there is an obvious point of attachment of the corn fruit to the cob. This structure corresponds to the stalk of the bean's flower and is the pathway through which the developing fruit received its nourishment.

On one side of a grain of corn is a light-colored, oval area that marks the location of the embryo. This is plainly visible through the fruit coat. Near the top of the kernel, on the same side


Silk scar
Cotyledon
Epicotyl
Hypocotyl
Point of attachment
Silk scar
Endosperm
Cotyledon
Epicotyl
Hypocotyl
Root cap
Point of attachment

26-8 The diagram shows the relation between the surface features and internal structure of the corn seed.


Calyx
Seeds
Ovary
Wall
POD—
LIMA BEAN
Style
Style
CAPSULE—IRIS
Ovary wall
Seed
SAMARA—
MAPLE
Ovary wall
and seed
coats
combined
GRAIN—CORN
Ovary wall
Seed
NUT—OAK
ACHENE—
SUNFLOWER

26-9 Various types of dry fruits.

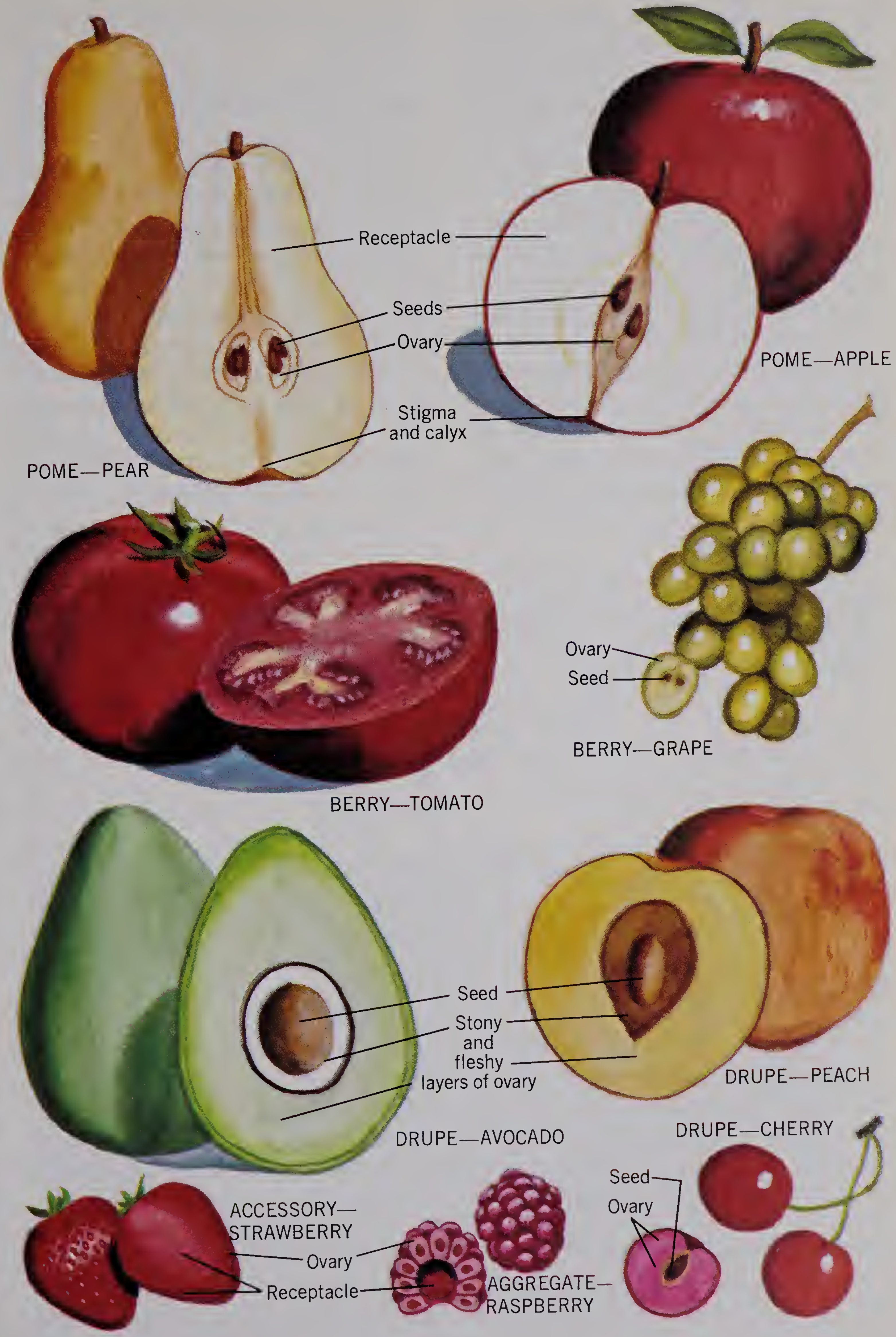
as the embryo, is a tiny point, the ***silk scar***, where the style was attached.

If you cut a grain of corn lengthwise through the region of the embryo, you can see the internal parts clearly, especially if you put a drop of iodine solution on the cut surface. The endosperm fills much of the seed (Fig. 26–8). This part of the seed developed from the endosperm nucleus after fertilization. The endosperm contains sugar and starch, and will turn blue when treated with iodine. This reaction indicates that there is a large quantity of starch present. The embryo, however, does not contain starch, but it does contain considerable protein. Sweet corn stores sugar in the endosperm, but field corn stores starch, which accounts for the fact that we eat the garden variety and not the other.

The embryo, consisting of a very small hypocotyl, an epicotyl, a cotyledon, and a radicle, lies on one side of

COMPARISON OF CERTAIN DICOTYLEDONOUS AND MONOCOTYLEDONOUS SEEDS

Bean	*Corn*
Testa with hilum and micropyle plainly visible	Hilum and micropyle covered by a three-layered fruit coat. The true seed coat lies inside of it
Two cotyledons	One cotyledon
Large embryo	Small embryo
No endosperm at time of dispersal	Large endosperm
Epicotyl fairly large	Epicotyl rather small
Epicotyl leaves folded	Epicotyl leaves rolled
The fruit is a pod, with several seeds	The fruit is a single grain, with one seed


Receptacle
Seeds
Ovary
Stigma and calyx
POME—PEAR
POME—APPLE
Ovary
Seed
BERRY—GRAPE
BERRY—TOMATO
Seed
Stony and fleshy layers of ovary
DRUPE—PEACH
DRUPE—AVOCADO
DRUPE—CHERRY
Seed
Ovary
ACCESSORY—STRAWBERRY
Ovary
Receptacle
AGGREGATE—RASPBERRY

26-10 Various types of fleshy fruits.

the corn grain. The radicle points downward, toward the point of attachment, and is surrounded by a protective cap. The epicotyl is also protected by a sheath or cap. The leaves of the epicotyl are rolled, not folded as they are in the bean, into a compact spear.

The corn has only one cotyledon, which is attached to one side of the very short hypocotyl and the epicotyl and lies against the endosperm. During germination the cotyledon digests and absorbs food from the endosperm, besides furnishing some of its own, and supplies it to the growing seedling. Notice that in the corn grain, most of the energy-producing food is stored outside the embryo rather than in the cotyledon, as we found in the bean.

Dormancy in seeds. Many seeds go through a rest period before they germinate. This rest period, or period of ***dormancy,*** may be a few weeks, an entire season, or several years. Many plants bear seeds in the fall and their seeds are normally dormant throughout the winter, but germinate during the following spring or summer.

Drought, cold, and heat are all enemies of the seedling, although it is enclosed in protective seed and fruit coats. When conditions are favorable for growth of a particular seed, however, the period of dormancy ends and ***germination,*** or sprouting, begins.

While some seeds may lie dormant for several years and still remain alive, there is a limit to the length of this period. Some seeds may live for almost 100 years in a dormant state and then germinate when conditions become satisfactory. On the other hand, some seeds, like the maple, germinate almost immediately after falling from the tree, with the result that you frequently see a large number of young maples starting to grow under the parent tree in the late spring.

In annuals that grow in colder climates, seeds are the only form in which the plants can survive the winter months. Their period of dormancy normally extends from one growing season to the next. The seeds of many perennials likewise lie dormant through the winter months and germinate the following spring or summer.

The ability of seeds to germinate is called ***viability.*** Seed viability depends on the conditions during dormancy and on the amount of food stored in the cotyledons and endosperm. Cool, dry places are ideal for storing seeds, while warmth and moisture lower viability. Commercial seed growers run viability tests and mark the results on various lots of seeds they sell. If you check the reported viability test, you can find out the percentage of germination to expect. If a lot of seeds has a viability of 92 percent, you can expect 92 seedlings from each 100 seeds you plant. Remember, however, that viability may vary since only relatively few representative samples are used in each test.

Conditions for germination. For germination, most seeds require at least three conditions: moisture, the correct temperature, and oxygen. The amount of each of these required varies greatly.

Seeds of many water plants germinate under water where there is plenty of moisture, a quite even temperature, and oxygen dissolved in the water. The seeds of most land plants cannot germinate under water.

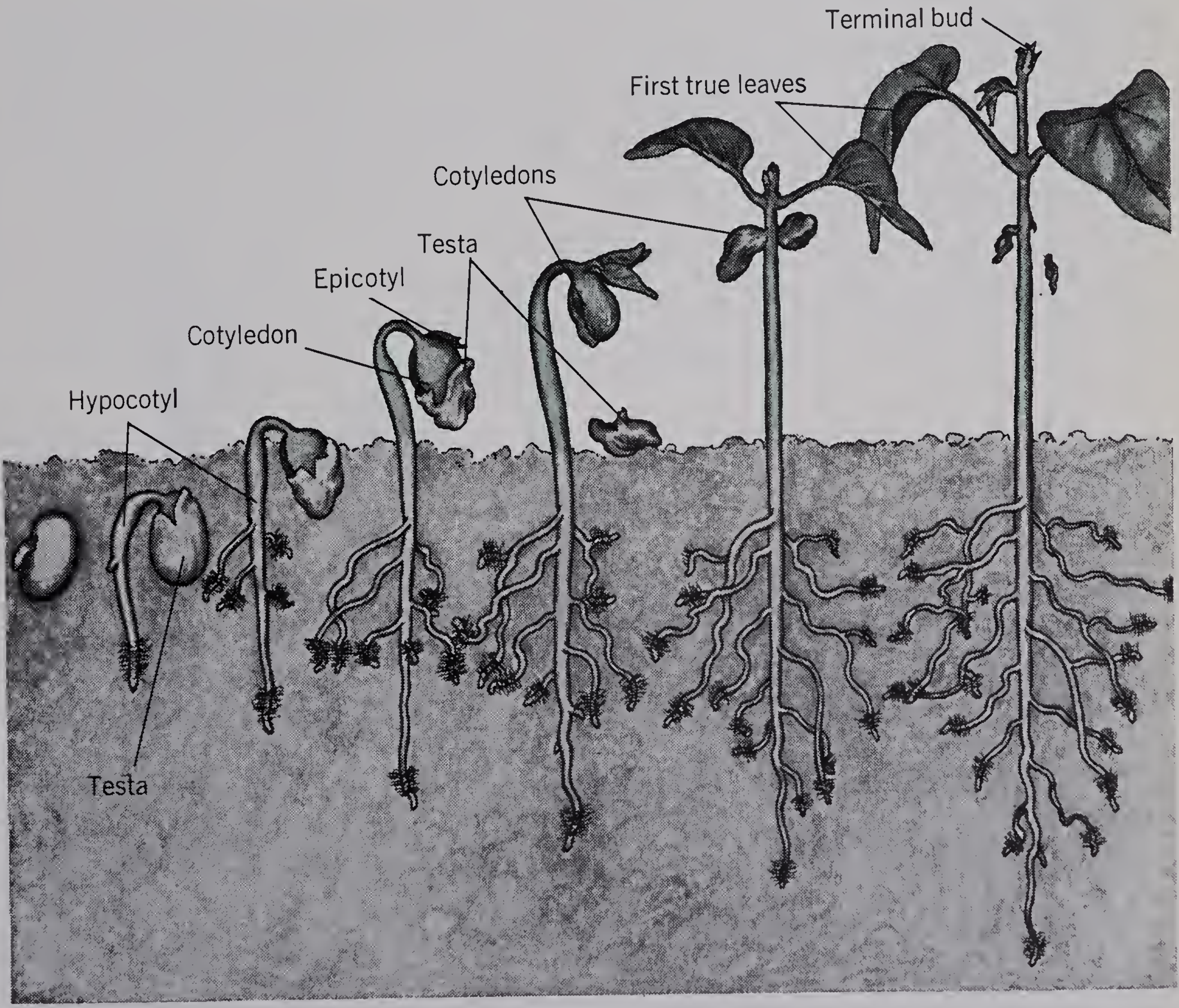
Before a seed germinates it usually absorbs considerable water, causing the seed to swell and soften its seed coats. But too much warm moisture during the growing season encourages the growth of fungi, which may cause the seeds to decay.

The temperature at which seeds germinate best is also variable. A maple seed can germinate on a cake of ice, but growth will be slow and survival very uncertain under these conditions. Others, like corn, require much higher temperatures, with a range of between 60° and 80° F being the most suitable for the majority of seeds.

During germination the cells of a seedling are dividing very actively. This increased activity requires a much higher rate of respiration than that of an older plant and you can see, therefore, why the oxygen supply to a seedling is critical. That is the reason the soil in a garden should be loose and the seeds planted sufficiently near the surface to give them an ample supply of oxygen.

Much of the food stored in the cotyledons or endosperm of a seed is starch. The plant changes this to sugar by the action of an enzyme known as ***amylase***, and the cells of the embryo absorb the sugar. This change accounts for the sweetish flavor of sprouting seeds and explains why sugar is extracted from sprouting grain (malt) or why soybean sprouts are sometimes used in cooking.

Growth of the seedling. The way in which the seed germinates and the seed-

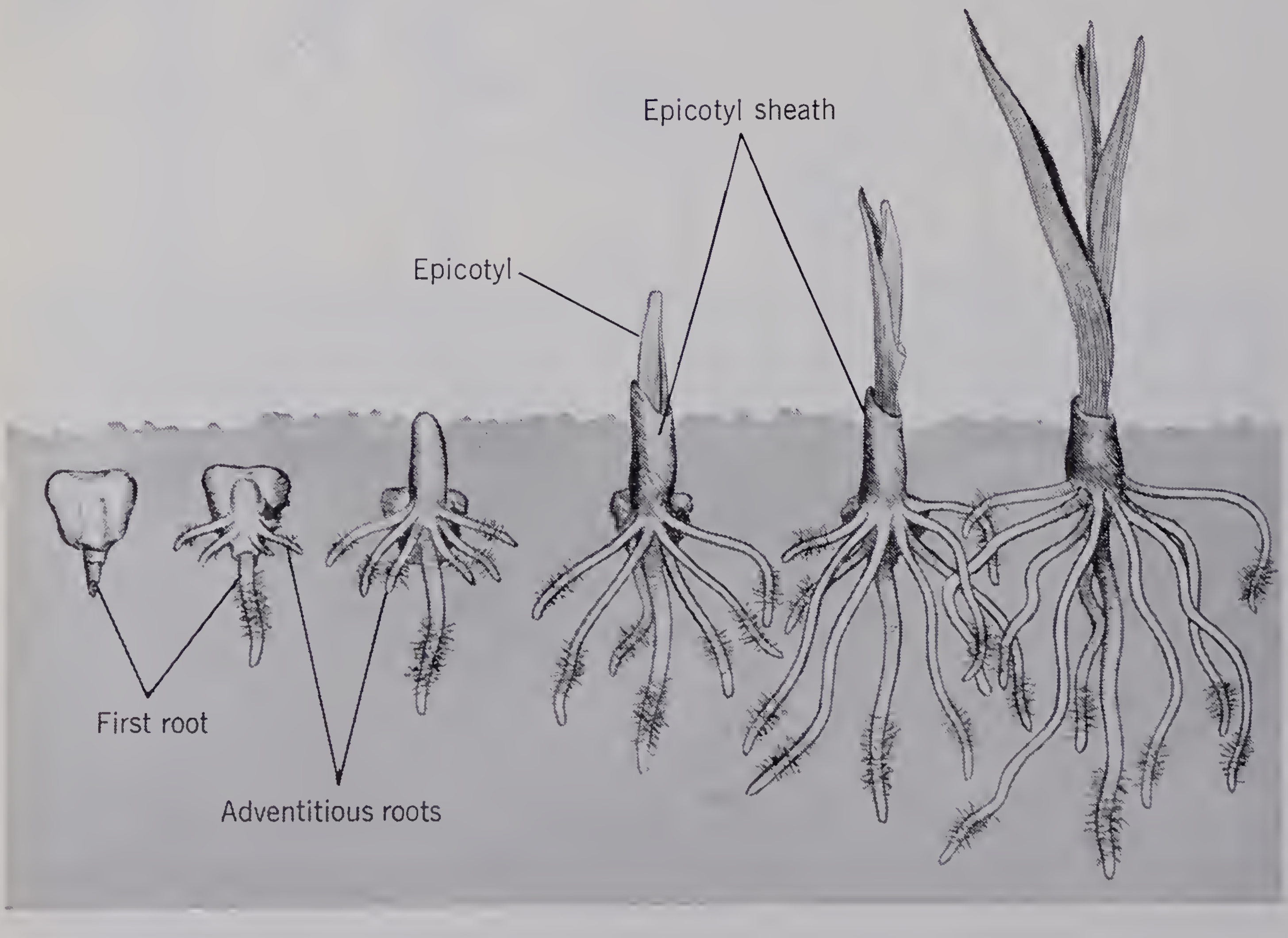


26-11 The various stages in germination of the bean seed. The cotyledons, which are a source of food for the growing seedling, finally fall off when the plant is able to produce its own food.

ling establishes itself varies in different kinds of plants and in the location of the seed during germination. If the seed is lying on the surface, the root must penetrate the soil from above, and the epicotyl will grow freely upward. If, on the other hand, the seed is completely buried, the epicotyl must grow through the soil and unfold its leaves above the surface while the root grows downward. We shall follow the stages in the germination of a bean seed and a grain of corn and see how this is accomplished. Few of us realize what an interesting process germination is because we have seldom stopped to think very much about it. But in a garden or on a farm, it takes place almost without our realizing it.

Figure 26–11 shows the stages in the germination of a bean. After the bean has absorbed water and softened its seed coats, the hypocotyl grows out through the seed coat. The root grows downward and forms the primary root of the seedling, while the hypocotyl is growing upward and forming an arch which pushes its way to the surface. After the hypocotyl arch appears above the ground, it straightens out and lifts the cotyledons upward. The cotyledons turn outward and release the epicotyl, which grows upward to form the shoot. Then the minute leaves unfold, forming the first foliage leaves of the plant. These are true leaves and are retained throughout the life of the plant which, in this case, is an annual. The plant dies after it has matured its fruit.

The stem lengthens rapidly, developing more leaves, and the small bud that was between the epicotyl leaves of the seed becomes the terminal bud of



26-12 In germination of the corn seed, neither the hypocotyl nor the cotyledon grows above the ground.

the plant. The cotyledons remain attached to the stem for a time, below the true leaves. But as the plant becomes better able to supply its own food by photosynthesis, the cotyledons wither and finally fall off.

The corn embryo also takes in water after it has been planted and its root pushes through the softened fruit and seed coats. This forms a temporary primary root which is soon added to by branch roots that develop from the primary root and later from the bottom of the stem. The leaves of the epicotyl, which are tightly rolled and encased in a sheath, penetrate the surface of the soil. After reaching the surface, the leaves unroll and the stem continues its growth upward to form the cornstalk. Neither the hypocotyl nor the cotyledon of a corn grain grows above the surface of the soil, as was the case in the germination of the bean (Fig. 26–12).

You need not worry about a root growing upward and a shoot entering the soil if you happen to plant a seed upside down. The lower part of the hypocotyl has a strong positive response to gravity, and the epicotyl an equally strong negative response.

IN CONCLUSION

The flower is an organ specially adapted for reproduction in angiosperms. Pollen develops in the stamens, and cross-pollination may be brought about by insects, wind, or water.

After fertilization the flower has served its function. The sepals and petals fall off (though sometimes the sepals remain as part of the fruit). The stamens wither, and all that is left is the pistil. Its ovary develops rapidly and becomes the fruit. Inside the ovary most of the fertilized ovules mature and become seeds. Each seed contains a tiny embryo and a substantial food supply. Whether the embryo plant will ever grow out of its covering depends on the environmental conditions at its landing place.

BIOLOGICALLY SPEAKING

amylase
anther
antipodals
calyx
corolla
cotyledon
cross-pollination
dormancy
egg
embryo
embryo sac
endosperm
endosperm nucleus
epicotyl
filament
generative nucleus
germination
hilum
hypocotyl
megaspore
megaspore mother cell
micropyle
microspore
microspore mother cell
ovary
ovule
pedicel
petal
pistil
polar nucleus
pollen
pollen sac
pollen tube
pollination
radicle
receptacle
seed dispersal
self-pollination
sepal
silk scar
sperm nuclei
stamen
stigma
style
synergid
testa
tube nucleus
viability

QUESTIONS FOR REVIEW

1. The sepals and petals of a flower are often spoken of as accessory parts. What purpose do they serve?
2. How do microspore mother cells differ from microspores in chromosome content?
3. Describe the formation of megaspores in an ovule.
4. Identify the eight nuclei present in the embryo sac at the time of fertilization.
5. Name three common agents of cross-pollination.
6. Describe the growth of the pollen tube after pollination.
7. Describe the fertilization of the egg and the triple fusion that produces the endosperm nucleus.
8. What part of the seed is produced from the zygote? from the endosperm nucleus?
9. Explain the relation between the flower and the fruit.
10. Name several ways in which the fruit serves the seeds that are enclosed within it.
11. What method of seed dispersal is shown in pod fruits that twist and open suddenly?
12. Describe some of the various modifications of fruits for dispersal by animals.
13. Give several examples of fruits that are dispersed by the wind.
14. Name three conditions required for seed germination.
15. How does the young shoot of the corn plant force its way through the soil in which it grows?

APPLYING PRINCIPLES AND CONCEPTS

1. Most seed plants produce large quantities of pollen grains. In proportion to the amount of pollen produced, the number of ovules is very small. Why?
2. Why do most wind-pollinated trees flower in the early spring?
3. Discuss various characteristics of insect-pollinated flowers that serve as devices for attraction.
4. Discuss the importance of the pollen tube in reproduction of a flowering plant.
5. Compare and contrast the gametophyte and sporophyte generations in the mosses and in the angiosperms. Discuss the evolutionary significance of the differences.
6. A seed will not germinate until it has enough water to soften the seed coats. How is this an automatic safeguard against germination during unfavorable conditions?

7. Explain why seeds planted in heavy clay soil or set too deep may germinate very slowly, if at all.
8. Food is stored in many seeds as starch. During germination the starch is changed to sugar, by the action of the enzyme, amylase. Why is this change necessary?

RELATED READING

Books

Baldwin, Ernest. *An Introduction to Comparative Biochemistry.* Cambridge University Press, New York. 1962

Bold, Harold Charles. *Morphology of Plants.* Harper and Row, New York. 1957

Bonner, James and Galston, Arthur W. *Principles of Plant Physiology.* W. H. Freeman & Co., San Francisco, Calif. 1952

Brook, Alan. *The Living Plant.* Aldine Publishing Company, Chicago. 1964

Coulter, Merle. *The Story of the Plant Kingdom.* The University of Chicago Press, Chicago. 1964

Cronquest, Arthur. *Introductory Plant Science.* Harper and Row, New York. 1961

Fenton, Carroll Lane. *Plants That Feed Us.* The John Day Co., Inc., New York. 1956

Galston, Arthur W. *The Life of the Green Plant.* Prentice-Hall, Inc., Englewood Cliffs, N.J. 1961

Greulach, Victor and Adams, J. Edison. *Plants: An Introduction to Modern Botany.* John Wiley and Sons, Inc., New York. 1962

Hill, Albert F. *Economic Botany: A Textbook of Useful Plants and Plant Products.* McGraw-Hill Book Co., Inc., New York. 1952

Hyde, Margaret O. *Plants Today and Tomorrow.* Whittlesey House, McGraw-Hill Book Co., Inc., New York. 1961

Hylander, Clarence J. *The World of Plant Life,* 2nd Ed. The Macmillan Co., Chicago. 1956

Kreig, Margaret B. *Green Medium.* Rand McNally & Co., Chicago. 1964

Lane, Ferdinand C. *All About the Flowering World.* Random House, Inc., New York. 1956

Meyer, Bernard S. and Anderson, Donald B. *Plant Physiology,* 2nd Ed. D. Van Nostrand Co., Inc., Princeton, N.J. 1952

Milne, Lorus J. and Milne, Margery. *Plant Life.* Prentice-Hall, Inc., Englewood Cliffs, N.J. 1959

Northern, Henry T. *Introductory Plant Science.* The Ronald Press Co., New York. 1958

Overbeck, Johannes van and Wong, Harry J. *The Lore of Living Plants.* McGraw-Hill Book Co., Inc., New York. 1964

Peattie, Donald Culross. *A Natural History of the Trees of Eastern and Central North America.* Houghton Mifflin Co., Boston. 1950

Platt, Rutherford. *1001 Questions Answered about Trees.* Dodd, Mead and Co., New York. 1959

Riedman, Sarah. *World Provider: The Story of Grass.* Abelard-Schuman Ltd., New York. 1962

Sterling, Dorothy. *The Story of Mosses, Ferns and Mushrooms.* Doubleday and Co., Garden City, N.Y. 1955

Stoutenburg, Adrian. *Beloved Botanist.* Charles Scribner's Sons, New York. 1961

Taylor, Norman. *1001 Questions Answered about Flowers.* Dodd, Mead and Co., Inc., New York. 1964

Weisz, Paul. *Science of Botany.* McGraw-Hill Book Co., Inc., New York. 1962

Went, Frits W. and Editors of Life. *The Plants.* Time, Inc., Books, Chicago. 1964

Wilson, Carl and Loomis, Walter. *Botany,* Rev. Ed. Holt, Rinehart and Winston, Inc., New York. 1957

Articles

Grant, V. "The Fertilization of Flowers," *Scientific American.* June, 1951

Koller, Dov. "Germination." *Scientific American.* October, 1950

National Geographic Society. *The World in Your Garden.* The Society, Washington, D.C. 1957

Salisbury, F. B. "Plant Growth Substances." *Scientific American.* April, 1957

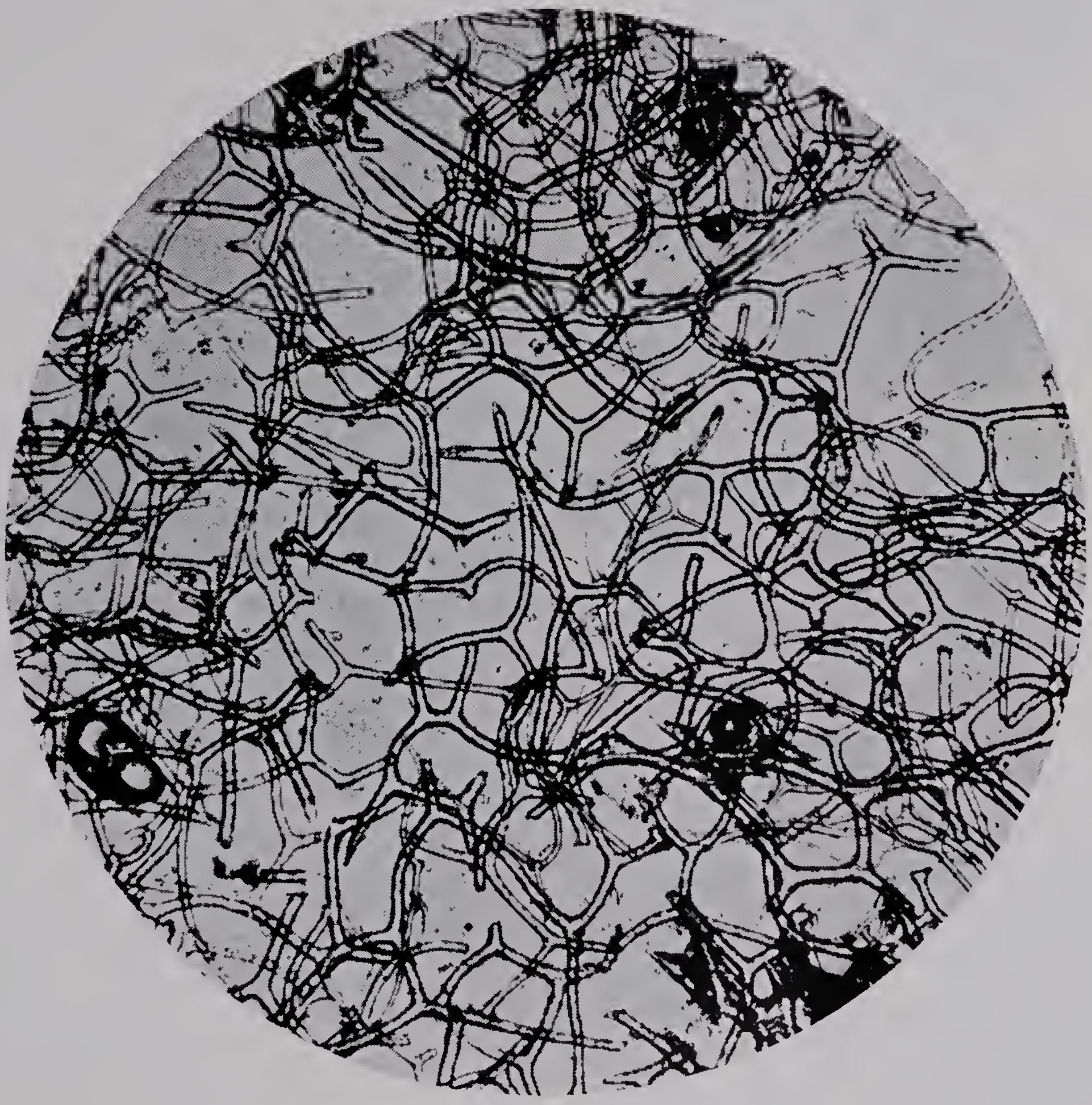
Schecken, V. "Plant Hormones." *Scientific American.* May, 1949

Wald, George. "Life and Light." *Scientific American.* October, 1959

Zahl, P. S. "The Evolution of Sex." *Scientific American.* April, 1949

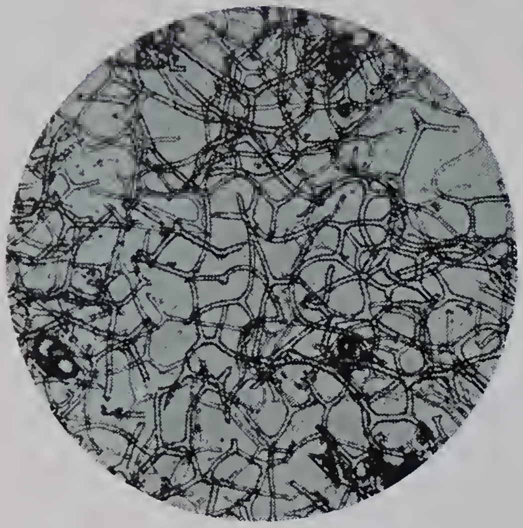
UNIT FIVE

BIOLOGY OF THE INVERTEBRATES



You are about to explore that great portion of the animal kingdom that lacks a backbone. Among these many and diverse forms of life, known as the invertebrates, you will find a variety of body structures and ways of life. The biologist views invertebrates with interest because they provide living answers to many questions about animal life. Where did animal tissues originate? When did hearts and circulatory systems, nervous systems, and digestive systems first appear? What is the origin of kidneys? Somewhere among the invertebrates you may find these and other answers to important questions about life.

CHAPTER 27



SPONGES AND COELENTERATES

The advantage of association. Do cells living in close association with one another have any advantage over those living independently? Perhaps we can answer this question by reviewing the story of Robinson Crusoe. After Crusoe's ship was wrecked, he found himself alone on an island. He had to catch and prepare his food. He had to make his clothes and shoes. He had to build shelter and protect himself from any enemies. Even though he learned how to do all these things, he could not devote enough time to any one job to excel in it. He was like a protozoan, in which one cell must perform all life activities without the aid of any other cells. On the other hand, if there had been ten men shipwrecked with Crusoe, each could have specialized in a job. One could have hunted food while another was building a house or making clothes for the group. They could have formed a small society having much greater efficiency than that of Crusoe's simple solitary existence. The many-celled animals that you will study in this unit and the next have just such an advantage over the protists — their cell specialization permits greater efficiency and in turn greater complexity.

Division of labor and interdependence. As you learned in your study of the cell in Unit One, increase in numbers allows for *division of labor,* as it would have on Robinson Crusoe's island. In the multicellular organisms, different cells become specialists in performing certain functions for the benefit of all the cells. The modification of a cell to perform a certain activity is *specialization.* As we study animals, from the simplest to the most complex, we shall find increasing cell specialization. As a result of this specialization, the animal is better able to adjust to its environment.

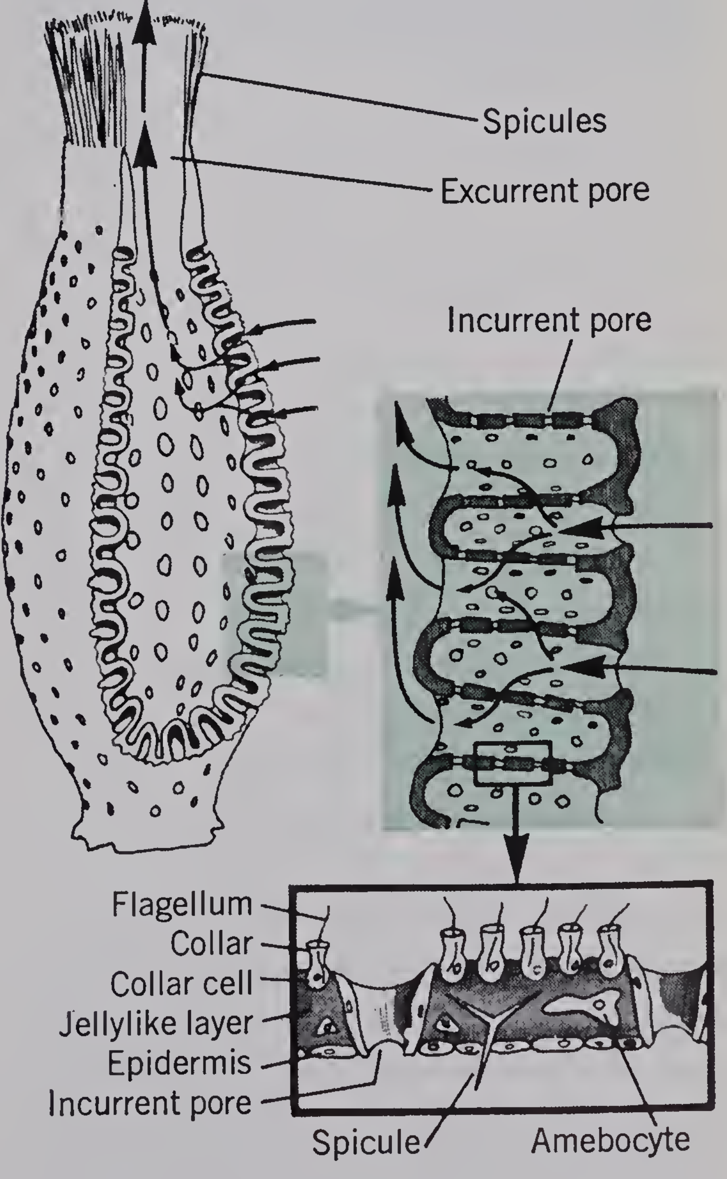
Division of labor and cell specialization result in the dependence of cells on one another, or the situation called *interdependence.* The man who devotes his life solely to one task is likely to lose the ability to do other necessary things. He depends on other specialists for help in those phases of his life. When cells are specialized for one activity, they become dependent on other cells for other activities. The ameba can live independently in a pond. But a muscle, nerve, or bone cell cannot live independently when removed from your body. Cell specialization is carried to the highest degree in the ***vertebrates,*** the subphylum to which man belongs. The vertebrates are animals with backbones; the ***invertebrates,*** which you will study in this unit, are animals without backbones.

The animal phyla. In man's attempt to study and understand living things, he searches for regularities. The regularities of living things are their characteristics. For example, the backbone is a characteristic conveniently used to separate the vertebrates from the invertebrates. Since about 95 percent of the animal kingdom is composed of invertebrates, other characteristics must also be used in classification. As you will learn, these regularities are important to the biologist in many ways. Similarities may indicate evolutionary relationships, but it should also be kept in mind that all living things must satisfactorily perform the life functions in order to survive. Therefore similarities also indicate common solutions to the problems of staying alive. As you read about the various animals, ask yourself — What important structural features place this animal in its group? Where does it live? How does it satisfy its organic needs? How does the environment affect it? How does it affect other organisms in the environment?

We shall study ten large phyla (*fy*-la) of animals. As you go along, you may wish to use the Appendix — a Classification of Organisms, found in the back of the book, for reference and review of the characteristics of each group and representative examples from them. You will notice that there are many more than ten animal phyla, and that there are certain classes within the ten phyla that we do not discuss. We shall limit our study to the largest and most important phyla, beginning our study with the sponge phylum, the simplest in the animal kingdom.

The sponges. Most sponges are marine, although there are a few fresh-water species. Living sponges may vary in color from white, gray, brown, red, orange, and yellow to purple and black. They may live singly or in colonies so massed that they make an encrusting layer over the surface of a rock. Sponges vary in size from a fraction of an inch to two yards in diameter.

When first looking at a living sponge, you might conclude, as Aristotle did, that it is an interesting plant. You might change your mind if you put a drop of India ink in the water near the sponge. You would see the ink particles pass into the body of the sponge and then reappear as if being forcibly expelled from the largest pore. The sponge, then, is doing something to set up currents. If you had time, a good microscope, and several sponges, you could determine that water passed into



27-1 Water is continually drawn into the sponge by the flagella of the collar cells. It passes through small pores into the spongocoel and out through the osculum.

27-2 The living brain coral and sea anemone shown are invertebrates which grow in the warm waters around the Bahama Islands. (Walter Dawn)

the sponge's body through small ***incurrent pores*** and out the larger ***excurrent pore,*** or *osculum* (*osk*-kyoo-lum). Fig. 27–1 shows the direction of water flow. Because of their many pores, the sponges are grouped into the phylum named ***Porifera,*** which means "pore-bearing."

Usually we think of an animal as being visibly and actively engaged in pursuing, catching, and eating its food. The sponge, however, is *sessile,* which means it is attached by the base, and must attract its food. A single sponge may circulate nearly a quart of water through its body every hour. Diatoms, small protozoans, bacteria, and other organic particles are brought to the sponge by the water. The sponge acts as a living filter by removing food and oxygen from the water. Carbon dioxide and wastes leave the sponge in the water that passes out the excurrent pore.

Let us take a closer look at the sponge to see how it is adapted for its submerged, sedentary way of life. A simple sponge consists of a hollow body, whose wall contains many tubes. The wall is formed by two layers of cells separated by a jellylike substance, loose cells, and ***spicules*** (*spik*-yools). The spicules are noncellular structures that form the skeleton and give support to the body of the animal. The classification of the sponges is based on the composition of these spicules. Some sponges have spicules composed of silicon, some of lime, and others of a tough but flexible substance called *spongin.*

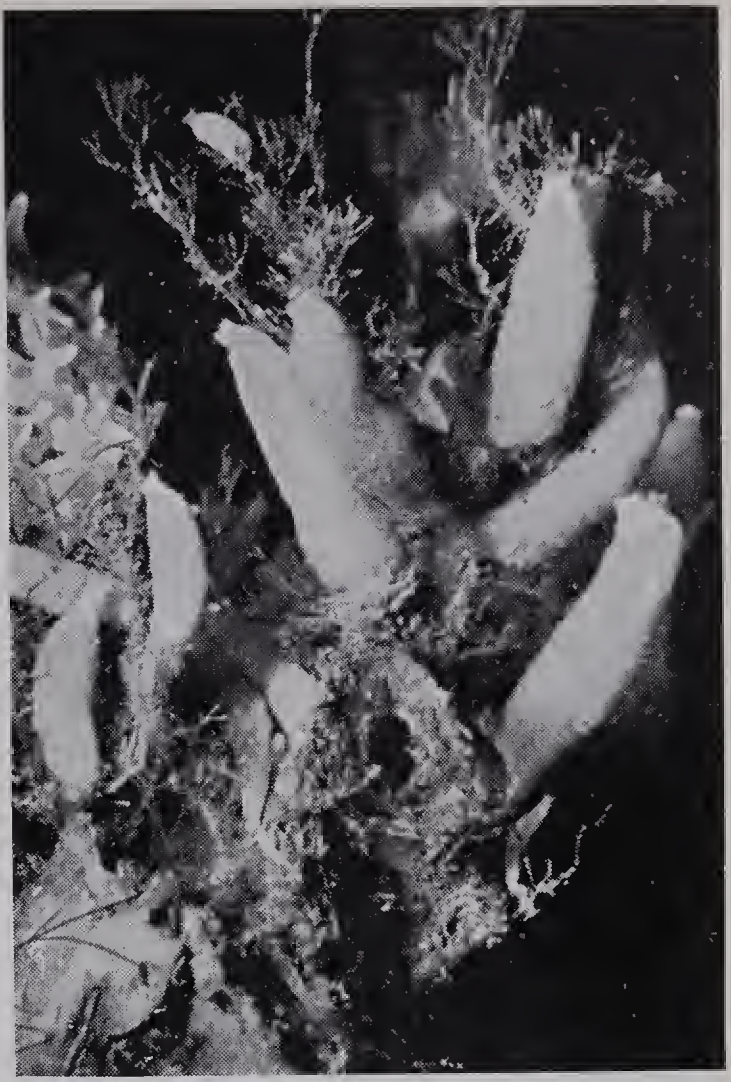
The outside layer or ***epidermis*** is protective. Many cells of the inside layer have curious cells with flagella projecting through them. The flagella of these ***collar cells*** set up the currents that draw water into the sponge. As food particles enter, they are caught by the collars and are digested by enzymes within the collar cells. From here digested food is absorbed by cells called ***amebocytes,*** because they resemble amebas. The amebocytes wander throughout the jellylike layer, transporting digested food and oxygen to the other cells. These wandering cells also carry wastes and carbon dioxide to the collar cells for disposal. Although sponges are often called loose aggregations of cells, you can see that there is sufficient interdependence to classify them as real multicellular animals.

Reproduction in the sponges. Sponges reproduce both sexually and asexually, in two ways. They may form ***buds,*** which are groups of cells that enlarge and live attached to the parent for a time, then break off and live independently. ***Gemmules*** (*jem*-yoo-ls) are cell masses surrounded by a heavy coat of organic material. During periods of freezing temperatures or drought, they are formed from little groups of amebocytes and a few spicules which break off from the parent sponge. When favorable conditions return, each gemmule grows into another sponge. Reproduction by gemmules is usually characteristic of fresh-water species.

Sexual reproduction occurs when eggs and sperm are produced. The sperm are shed into the water and enter another sponge through the incurrent pores. They are taken into the cytoplasm of the collar cells and then transferred to the ova by the wandering amebocytes.

Sponges are able to regenerate missing parts. For this reason sponge growers are able to make sponges multiply by cutting them in pieces, which are then placed in special growing beds. This is not a method of reproduction for it is not normally used by the sponge; this method is utilized by commercial sponge fishermen because it is much faster than budding.

Fresh-water sponges are small and of no commercial importance. Some marine sponges with spongin skeletons, especially those in warmer oceans, grow to be very large and are collected by divers and by drag hooks. The sponges are then piled on shore or hung on the rigging of the boat until the flesh has decayed. The remaining spongin skeletons are washed, dried, sorted, and sometimes bleached. They are then ready for marketing. Famous sponge fishing grounds include the Mediterranean and Red seas, the waters around the West Indies, and Tarpon Springs, Florida.



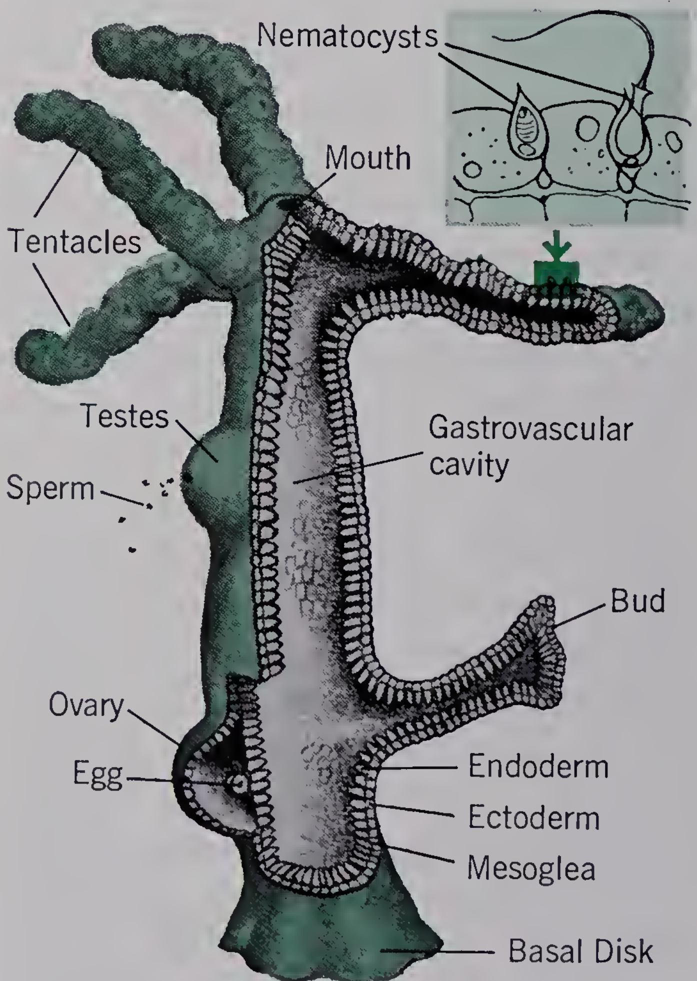
27-3 Simple sponges may be found growing in colonies in warm waters. (Walter Dawn)

The coelenterates. Many a pleasant swim in the ocean has turned into a painful experience when the swimmer was stung by a jellyfish. Strange indeed are these pulsating creatures which bob around in the ocean currents, dangling long, stringy tentacles under a floating, inflated sac. The phylum ***Coelenterata*** (si-*lent*-e-ra-ta) also includes the hy-

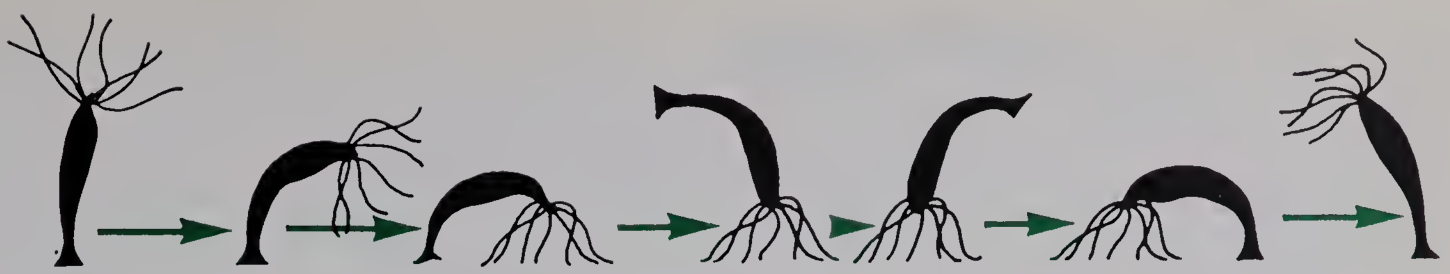
27-4 Sea anemones live in tidepools on rocky shores. (Ewing Galloway)

droids, corals, sea fans, sea anemones, and Portuguese man-of-war. Members of this phylum vary in size from microscopic forms to the largest jellyfish of the North Atlantic, which may reach 12 feet in diameter. Coelenterates live either as individuals or united to form colonies. All of these animals are aquatic — a few live in fresh water but most are marine.

The hydra. The characteristics of this phylum can be seen in *Hydra,* a genus of common fresh-water coelenterates. There are white, green, and brown species, which live in quiet ponds, lakes, and streams. The body of the hydra consists of two cell layers separated by a jellylike material called ***mesoglea*** (mez-uh-*glee*-a). The outside layer is the ***ectoderm,*** and the inner layer is the ***endoderm*** (Fig. 27–5). The baglike body of the animal has a single opening that is surrounded by ***tentacles*** bearing stinging cells, called ***nematocysts.*** Stinging cells are found only in the coelenterates. Hydras vary in size from less than a half inch, including the tentacles, to about an inch and a half. They are attached to rocks or water plants by a sticky secretion of their ***basal disks.*** Because of their small size, transparency, and habit of contracting into little knobs when disturbed, hydras are often overlooked. Yet they are abundant and are the only really successful organisms among the few members of their phylum that have invaded fresh water. A hydra may leave one place of attachment and float or move to another, or secrete a bubble



27-5 The external and internal structures of the hydra. The animal has two layers of cells with a jellylike material between them. Two stinging cells are shown enlarged at the upper right.

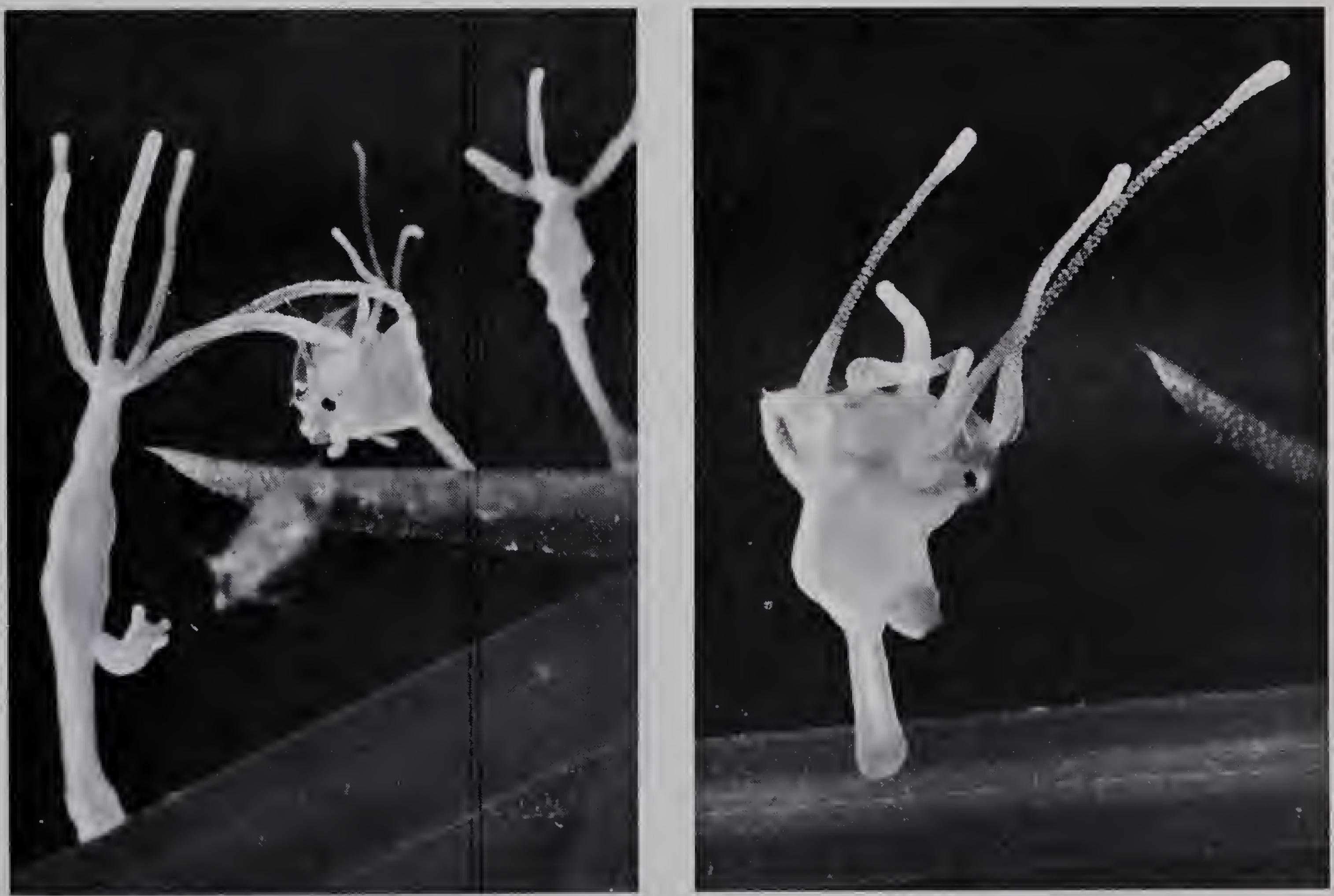


27-6 The hydra moves by a kind of somersaulting. It bends over, attaches its tentacles to the bottom, loosens its basal disk, swings the disk over its mouth, then attaches itself to the new bottom area. After loosening its tentacles it repeats the process.

at the base and float to the surface upside down. The hydra also moves in an odd somersaulting fashion (Fig. 27–6).

How the hydra gets food. When a small animal comes in contact with one of the tentacles of a hydra, many nematocysts explode and pierce the victim's body with tiny hollow barbs. Since each barb is attached to the tentacle by a thin thread, the combined effect of many threads prevents the escape of the hapless victim. At the base of each barb is a small poison sac which discharges its contents through the hollow barb and into the prey, thus paralyzing it.

Once the prey has been stilled, the tentacles bend inward and push it through the circular mouth and into the body cavity. Specialized endodermal cells line this space and function in digestion and absorption. For this rea-



27-7 The hydra uses its tentacles to capture and paralyze its prey. At the right the victim is shown inside the body cavity. (Charles Walcott) son the space is called a ***gastrovascular cavity.*** The digestive wastes are then expelled through the mouth. The mouth and digestive cavity of the coelenterate are considered to be advances over the feeding structures of the sponge as they allow a greater range in the types and sizes of food available to the animal.

The behavior of the hydra. We have now observed one reaction of a coelenterate which shows a definite advance over the more primitive sponge. The tentacles are coordinated in catching and pushing food into the mouth. Also, if you touch a tentacle of an extended hydra with a needle, all the tentacles and the body contract suddenly. The stimulus to one tentacle travels to cells of the other tentacles and to the body through a series of nerve cells, called the ***nerve net,*** which lies in the mesoglea. The contraction itself is accomplished by slender fibers lying in the ectoderm, and these can be compared to the muscle cells of higher animals. The hydra has no real nervous system such as that found in higher animals, and it has no brain.

Reproduction in the hydra. The hydra accomplishes *asexual reproduction* by forming *buds.* A bud appears first as a knob growing out from the side of the adult. Later this knob develops tentacles, and after a period of growth it separates from the parent and lives independently. In this method of reproduction the bud is a small outgrowth of endoderm and ectoderm and is capable of growing into a new organism (Fig. 27–5). In a plant, the bud is an undeveloped shoot which will elongate the stem or develop leaves or a flower; but it will not become a whole new organism.

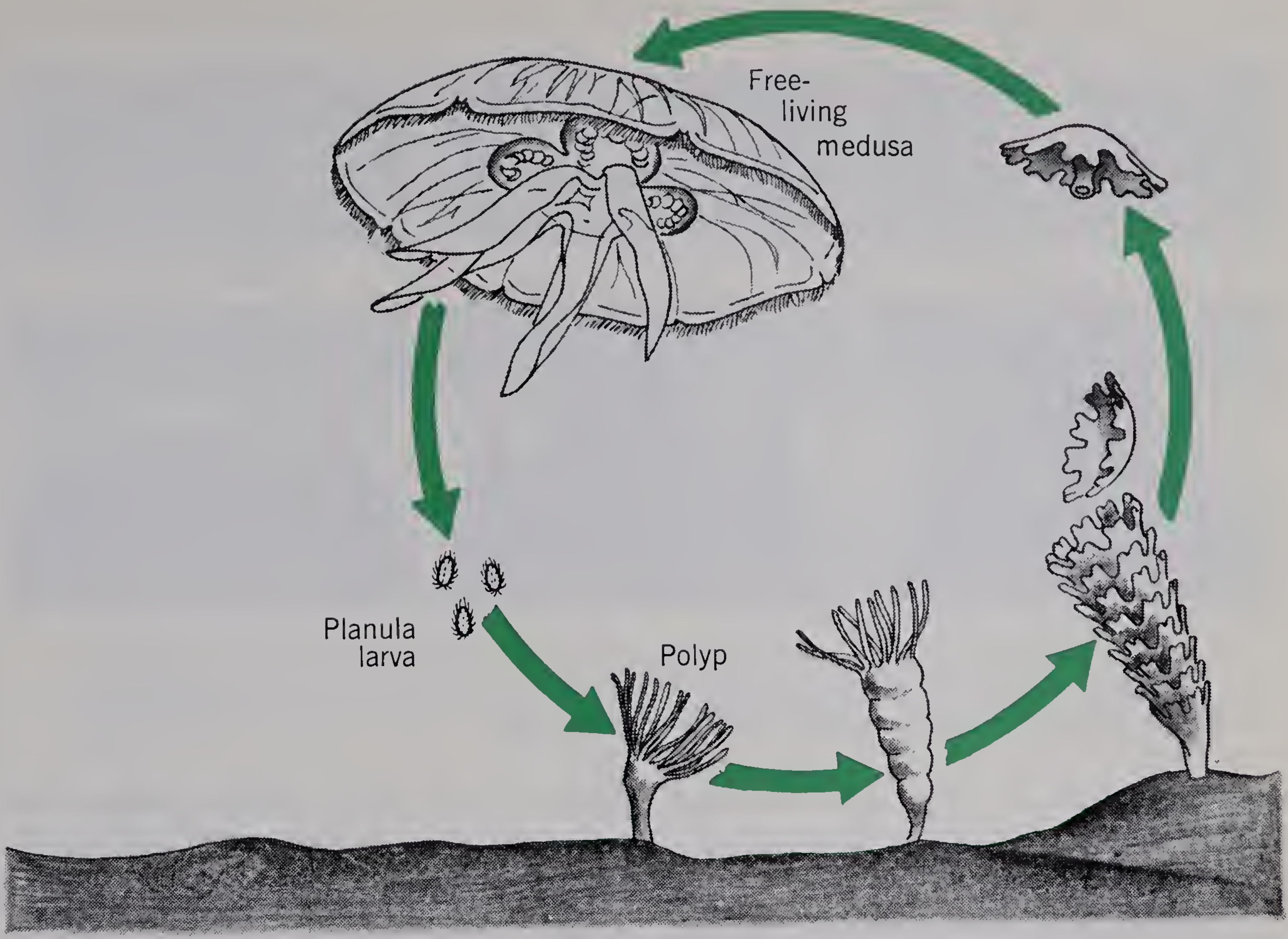
Also, like the sponge, the hydra has remarkable powers of regeneration. If a hydra is cut into pieces, each piece will regenerate the missing parts and become a whole animal.

Sexual reproduction usually occurs in autumn. The eggs are produced along the body wall in little swellings called ***ovaries;*** the sperm cells are formed in similar structures called ***testes.***

The egg is fertilized in the ovary, and the zygote grows into a spherical, many-celled structure with a hard, protective cover. In this stage it leaves the parent and goes through a rest period before forming a new hydra.

Two ways of life. The body form of a coelenterate may be one of two types. The ***polyp*** form is well illustrated by the hydra, with its tubular body attached to the bottom at one end with tentacles at the other end. The bell-shaped, free-swimming form found in the jellyfish is called a ***medusa.*** A medusa swims by

27-8 The mouth of the jellyfish is in the center of the "bell," but is usually obscured by the tentacles, which sting the victim to be eaten. (Hermes from National Audubon Society)



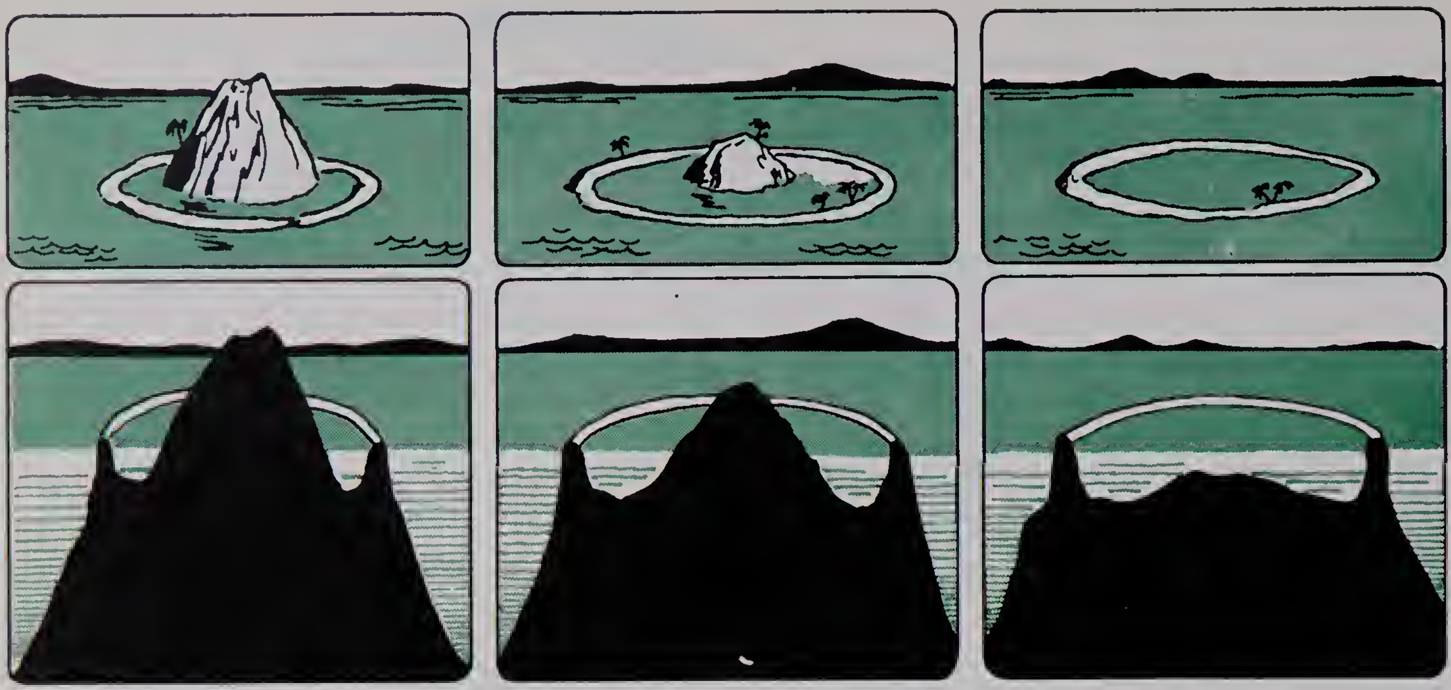
27-9 The life cycle of *Aurelia* is shown in this diagram.

taking water into the cavity of the bell and then forcibly ejecting it. This jet propulsion produces a jerky movement through the water.

An interesting example of a coelenterate that occurs in both the medusa and the polyp forms may be found in *Aurelia,* a common jellyfish. The sexually-reproducing medusa has a scalloped margin from which protective tentacles hang (Fig. 27–9). The male medusas shed sperm into the sea where the sperm may enter the gastrovascular cavity of a female. Here they fertilize eggs which have been released by the female. The zygotes are protected for a short time by folds of tissue surrounding the mouth.

When the young are released, they are small, oval-shaped, ciliated larvae called *planulae* (sing. *planula*). The planula is the beginning of the asexual phase in the life cycle of *Aurelia.* After swimming about for a short period of time, it attaches to a rock or seaweed, develops tentacles, begins feeding, and is then a polyp. The polyp grows and forms more polyps by buds that form at the base. In fall and winter, however, the polyp elongates and forms many horizontal divisions until it resembles a pile of saucers. One by one the uppermost "saucer" breaks loose and swims away to develop into the adult sexually-reproducing medusa. The *Aurelia* is thus one coelenterate having two different forms — the polyp and the medusa — both of which reproduce.

Other coelenterates. The *coral* is the only coelenterate of economic importance. Its body is a small, flowerlike polyp only a fraction of an inch long. Most coral polyps live in colonies and build skeletons of lime which they ex-



27-10 The drawings show three different kinds of coral reefs. Left: the marginal type grows around an island. Center: the barrier reef that is widely separated from the land. Right: an atoll with an open lagoon.

tract from the sea. This lime skeleton is firmly cemented to the skeleton of a neighboring polyp. When one animal dies, its skeleton remains for the attachment of another. Lime skeletons of corals thereby increase in size until a single mass may support many thousands of animals living on the surface of the skeletons of their ancestors. In some species, these masses are solid, while other corals build delicate and intricate fan-shaped structures.

Over a period of time, large coral reefs are built up. These are most common in the warm shallow oceans and may be of three types: 1. the *marginal type*, close to the beach; 2. the *barrier type*, forming a ring around an island with a wide stretch of water between the beach and the reef; or 3. a ring with an open lagoon in the center, called an *atoll* (Fig. 27–10).

The Great Barrier Reef off the northern coast of Australia extends about 1,260 miles parallel to the coast. It is about 50 miles wide. The extent of coral formations became apparent during World War II when coral was found to be useful in the construction of airstrips and roads. Coral jewelry may be found in shops all over the world. Some corals are also bleached and dyed various colors to be used in flower arrangements or for decorations in homes.

After storms on the Pacific coast, the beaches may be covered with bluish membranelike animals measuring two or three inches in length. They are called purple sails, or *Velella*. Related to the purple sail is the *Physalia*, or Portuguese man-of-war. These two organisms are actually colonies of coelenterates hanging from a float which keeps them near the surface and is moved through the water by the wind. The individual organisms are polyps, and each has a special function to perform for the colony. Some are feeding polyps and digest food caught by the food-getting polyp, while other polyps function in gamete production. Although the Portuguese man-of-war is largely tropical or semitropical, it is found in the Gulf Stream and occasionally drifts to the British coast.

IN CONCLUSION

Although the sponges are considered multicellular animals, they are not as advanced as the coelenterates, in which you have observed cell specialization allowing for coordinated action. With the development of tissues, the cells become almost completely dependent upon the various activities and functions of other cells.

In the next chapter we shall continue our consideration of the invertebrate phyla with the three groups classified as worms. As you will see, an elongated body is about the only characteristic the various worms have in common.

BIOLOGICALLY SPEAKING

amebocyte
basal disk
buds
Coelenterata
collar cell
ectoderm
endoderm
epidermis
excurrent pore
gastrovascular cavity
gemmule
incurrent pore
invertebrate
medusa
mesoglea
nematocyst
nerve net
ovaries
polyp
Porifera
spicules
tentacles
testes
vertebrate

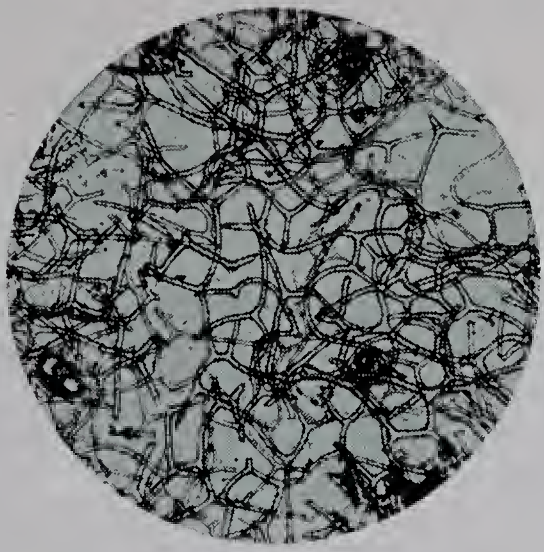
QUESTIONS FOR REVIEW

1. How does the multicellular condition permit such an efficient division of labor?
2. What are the major structural characteristics which distinguish the sponges from the coelenterates?
3. In what kinds of environments would you expect to find specimens of sponges? Where would you expect to find specimens of hydra? Do you think the size of the animal body has anything to do with the particular habitats of these two groups of organisms?
4. Compare the feeding methods of a sponge and a hydra. How are they alike and how do they differ?
5. Give examples of regeneration in sponges and coelenterates.
6. In what ways are the *Aurelia* and hydra similar? In what ways are they different?
7. What is the function of the nematocysts?
8. Describe the formation of a coral reef. What are the three types of coral reefs?
9. Why are the purple sails and the Portuguese man-of-war considered to be so much more highly specialized than any of the other coelenterates you have studied thus far?

APPLYING PRINCIPLES AND CONCEPTS

1. Compare the ways in which cell specialization is similar to division of labor in modern civilization.
2. Why is it essential that a jellyfish be hollow?
3. How is knowledge of the regeneration capabilities of sponges used commercially?
4. How do you account for the fact that some sponges die when exposed briefly to air, even when promptly returned to water?
5. Would you consider a sponge to be a more primitive form of life than a coelenterate? Give reasons for your answer.
6. How do the Porifera and Coelenterata spread to new habitats? What conditions do you believe would be most favorable for their growth?

CHAPTER 28

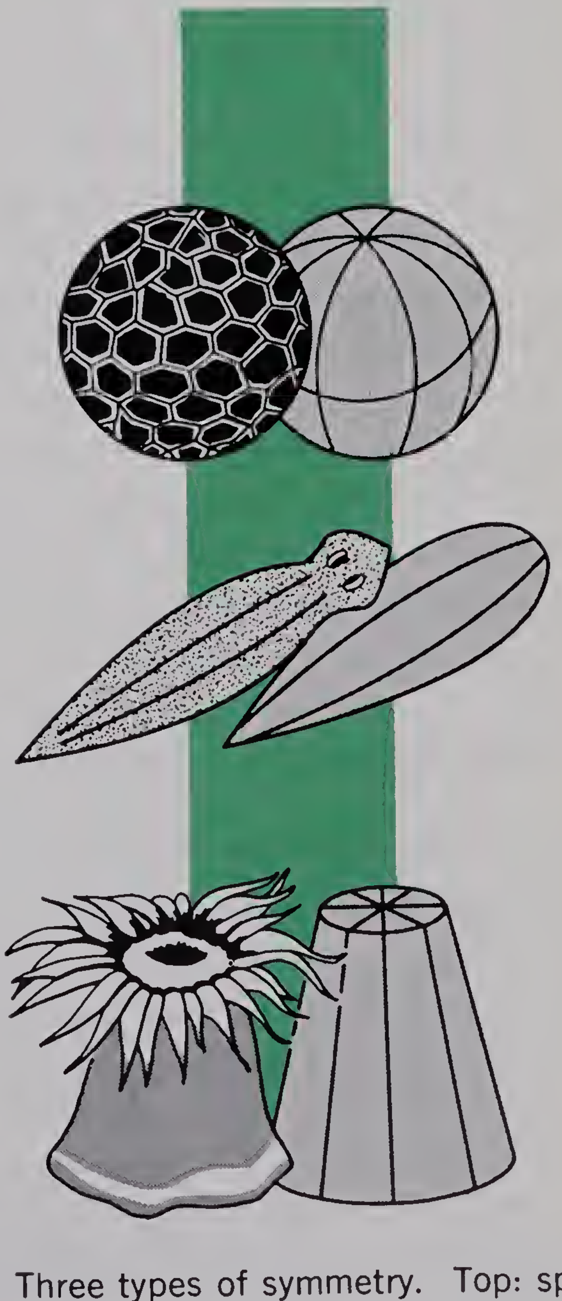


THE WORMS

Body form in organisms. Let us begin our study of the worms by reviewing the general forms of organisms. Those that have no definite shape, such as the ameba and many sponges, are said to be ***asymmetrical.*** All other organisms have a definite form and are symmetrical. The radiolarians and *Volvox* are protists with ***spherical symmetry.*** They may be divided into two equal parts by any plane passing through the diameter of the body. A baseball is a good example of a spherically symmetrical object. Organisms with spherical symmetry often lack an efficient mode of locomotion and usually float on or near the surface of the water.

Radial symmetry is best demonstrated by the sea anemone, which is pictured in Fig. 28–1. This coelenterate has a central disk from which tentacles radiate out like spokes of a wheel. The central axis is formed by the mouth and passes through the center of the body. The animal may be divided into two equal parts by any plane that passes through the diameter of the disk and through the central axis. Some simple sponges, most coelenterates, and most adult echinoderms (which we shall study in Chapter 29) are radially symmetrical. This type of symmetry allows the stationary animal to encounter food and enemies from all sides.

Bilateral symmetry is exhibited by the higher animals. It means, literally, "two-sided shape." Only one plane can separate animals with this kind of symmetry into two similar parts. This plane must pass through the longitudinal axis, through the center of the back, and through the center of the front. This would not divide the animal into iden-



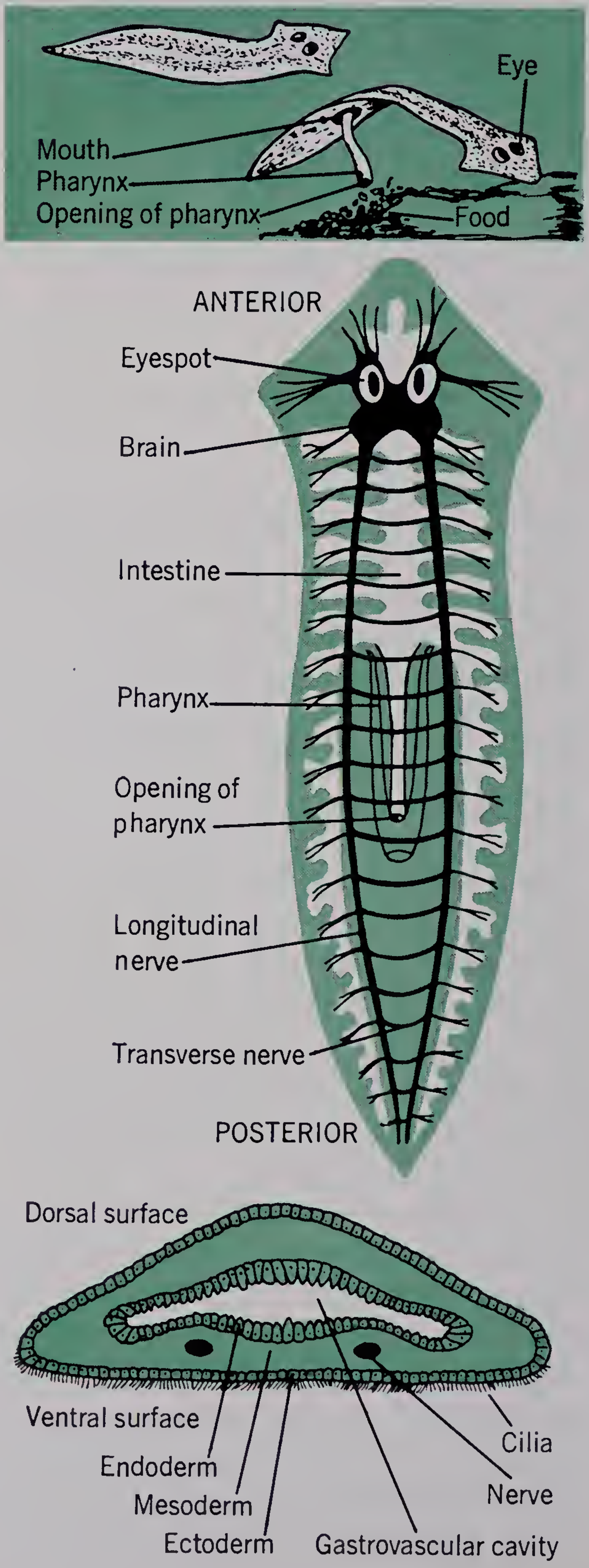
28-1 Three types of symmetry. Top: spherical; middle: bilateral; bottom: radial.

tical parts, but the pieces would be mirror images. Animals with bilateral symmetry have a definite right and left side; they have an upper, or ***dorsal,*** surface and a lower, or ***ventral,*** surface; they have a definite ***anterior*** and ***posterior*** end. All the vertebrates and many invertebrates have this type of shape. The anterior end usually contains a concentration of nervous tissue and the sense organs for testing the environment.

Diversity among the worms. The worms we shall study are divided into three phyla (see Appendix). The least complex of these is the ***Platyhelminthes*** (plat-i-*hel*-minth-ez), or flatworms. These flat-bodied animals have two layers of cells, the ectoderm and endoderm, like the coelenterates, but in addition they have a middle layer called the ***mesoderm.*** All the tissues and organs of the body develop from these three layers of cells. This will also be true in all the other animals we shall study, including man. The flatworms consist of three classes: the *Turbellaria,* the *Trematoda,* and the *Cestoda.*

A free-living flatworm. The ***Turbellaria*** are the free-living flatworms of which Planaria is the most common example. When biologists say that an organism is *free-living,* they mean that it is not parasitic. Planarians are aquatic and are found under stones in fresh-water ponds and streams. The next time you are out collecting, tie a string to a piece of liver and leave it on a rock for a few hours. Bring the rock into class and put it in an aquarium filled with pond water. You will probably find many of these worms crawling on the glass of the aquarium the following day.

Planarians range from a quarter to a half inch long and vary in color from black or brown to white. They are bilaterally symmetrical, blunt at the anterior end and pointed at the posterior.


Eye
Mouth
Pharynx
Opening of pharynx
Food
ANTERIOR
Eyespot
Brain
Intestine
Pharynx
Opening of pharynx
Longitudinal nerve
Transverse nerve
POSTERIOR
Dorsal surface
Ventral surface
Cilia
Endoderm
Nerve
Mesoderm
Ectoderm
Gastrovascular cavity

28-2 The center drawing shows the digestive and nervous systems of the planarian and that at the bottom a cross-sectional view of the animal.

The two ***eyespots*** on the anterior end are responsible for its nickname, "the cross-eyed worm." These eyespots are *photosensitive* — that is, light striking them stimulates nerves in this area and the animal can act accordingly. Planarians usually avoid bright light, and are therefore said to be negatively *phototropic* (foht-uh-*trohp*-ik).

The ***pharynx*** (*far*-inks) is a tube located on the ventral surface of the animal (Fig. 28–2). When extended, this tube sucks up microscopic particles which may include tiny living organisms. Since planarians clean up the water by eating organic matter, they are considered scavengers. When food is drawn into the digestive cavity, it enters one of the three main branches of the ***intestine*** and then passes to one of the smaller side branches. Cells lining the intestine receive the food and digest it in vacuoles. Digested food passes to all body tissues by diffusion. Indigestible waste materials are excreted through the pharynx and mouth opening. Cellular wastes are collected by tubules that branch throughout the animal and open to the surface by several tiny pores.

Compared to the animals we have studied so far, the nervous system is well developed in planarians. A mass of nervous tissue, the brain, lies just beneath the eyespots. The concentration of nervous tissue at the anterior end is called *cephalization* (*sef*-a-li-*zay*-shun). Many nerves from the anterior region lead directly to the brain. In a bilaterally symmetrical organism this arrangement of nerves is very important. As the worm moves, its head end is able to receive stimuli of chemicals, water currents, touch, light, and heat. The planarian is thus able to test the environment so that if unfavorable conditions exist, it can turn around. For this reason the concentration of *receptors* (receivers of stimuli) and nerves in the anterior end of a bilaterally symmetrical organism is of survival value.

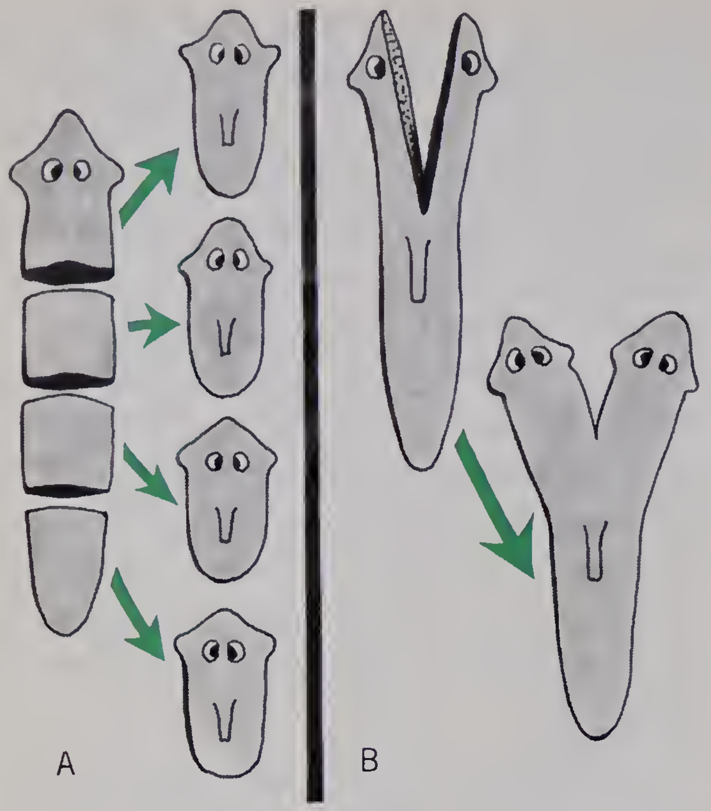
The ***longitudinal nerves*** run along either side of the body near the ventral surface. These nerve cords are connected by ***transverse nerves,*** giving the nervous system a ladderlike appearance. From the surface area many small nerves go to the longitudinal nerves. This type of nervous system allows the planarian to have coordinated movement, as well as to respond to stimuli on all parts of the body.

When watching planaria in a glass dish or an aquarium, you will see that they have two distinct motions. One is a muscular movement whereby the anterior end of the body moves from side to side. The other is a forward gliding motion that is accomplished by almost imperceptible muscular contractions aided by cilia on the ventral surface.

Reproduction in the planarian is accomplished either asexually by fission or sexually by gametes. Each animal is ***hermaphroditic,*** which means that it possesses both male and female reproductive organs. Cross-fertilization occurs, and the eggs are then shed in capsules. The capsules, usually containing less than ten eggs, are often attached to rocks or twigs in the water. In two or three weeks the eggs hatch and minute planarians emerge.

Like the sponges and many coelenterates, some planarians have remarkable powers of regeneration. Some will regenerate complete worms from almost any piece (Fig. 28–3). The parasitic flatworms, however, have no ability to replace lost parts. This is true of parasitic animals in general.

The parasitic way of life. Usually when we speak of evolution we think of



28-3 Regeneration in the planarians.

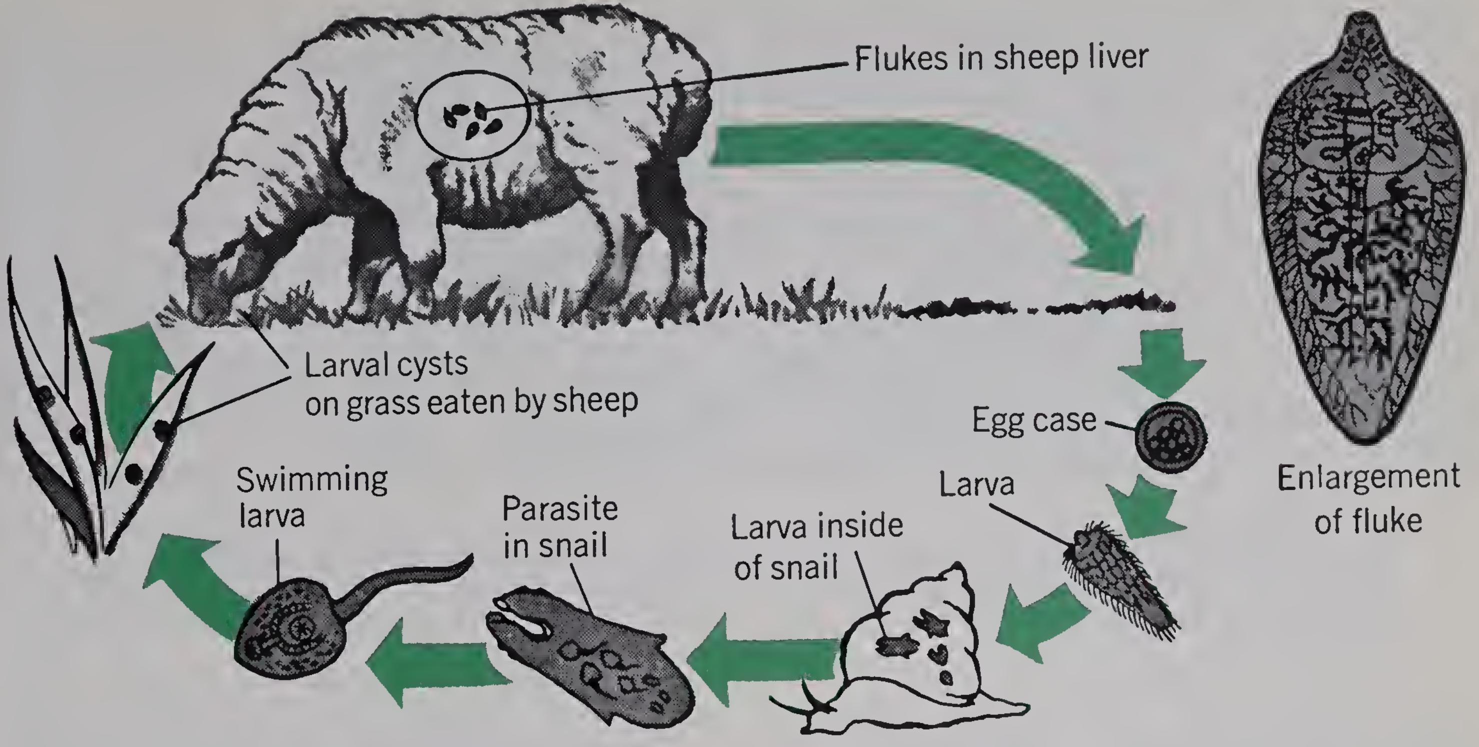
forms increasing in complexity as they adapt to environmental changes. But a parasite living within the body of another animal is faced with problems not at all like those of its free-living relatives. The size of a parasite is limited by the size of its host. If it were to grow to a large size, it would kill its host and find itself without a home. Intestinal parasites usually have hooks or suckers by which they can cling to the walls of the intestine. This feature prevents them from being swept away with the movement of the intestinal contents. The environment literally bathes the parasite with already digested food from which it can merely absorb its nutrients. The parasite is protected against being digested itself by a thick, resistant cuticle which its free-living relatives may not have.

Since certain systems are reduced or lost in the parasitic worms, we say that the worms have ***degenerated.*** The tapeworm, for example, has no digestive system. This is actually a benefit to the parasite, as it does not need a digestive system, and the resulting space may be used for developing eggs.

The way in which the parasitic worms develop is called a life history. Dispersal is a problem to the internal parasite, and larval forms may be free-living or may involve a stage of life within another kind of organism. Let's look at the life histories of some common parasitic worms.

The flukes. The class ***Trematoda*** includes the *flukes,* which are parasites in many animals, including man. Flukes differ from planarians in that they have no external cilia in the adult. Since cilia are structures of locomotion, their lack is in keeping with the parasitic way of life. Flukes have a thick *cuticle* and one or more *suckers,* which are used to cling to the tissues of the host. The anterior sucker surrounds the mouth, which opens to a short pharynx. Although the nervous system is similar to that of the planarian, there are, as might be expected, no special sense organs. Most of the flukes have a highly developed reproductive system and are hermaphroditic. Besides the fact that this system occupies a larger percentage of the body, the fluke differs from the planarian in having a ***uterus.*** The uterus is a long coiled tube which stores large numbers of eggs until they are ready to be discharged through the *genital pore.*

The flukes have complicated life histories, usually involving a snail and one or more other hosts. The sheep-liver fluke, for instance, lives as an adult in the liver and gallbladder of sheep. Eggs pass from the gallbladder to the intestine. If they fall into water after they are eliminated by the sheep, they hatch into young worms called ***larvae*** (sing. *larva*), which enter the body of a particular kind of snail. In the snail,



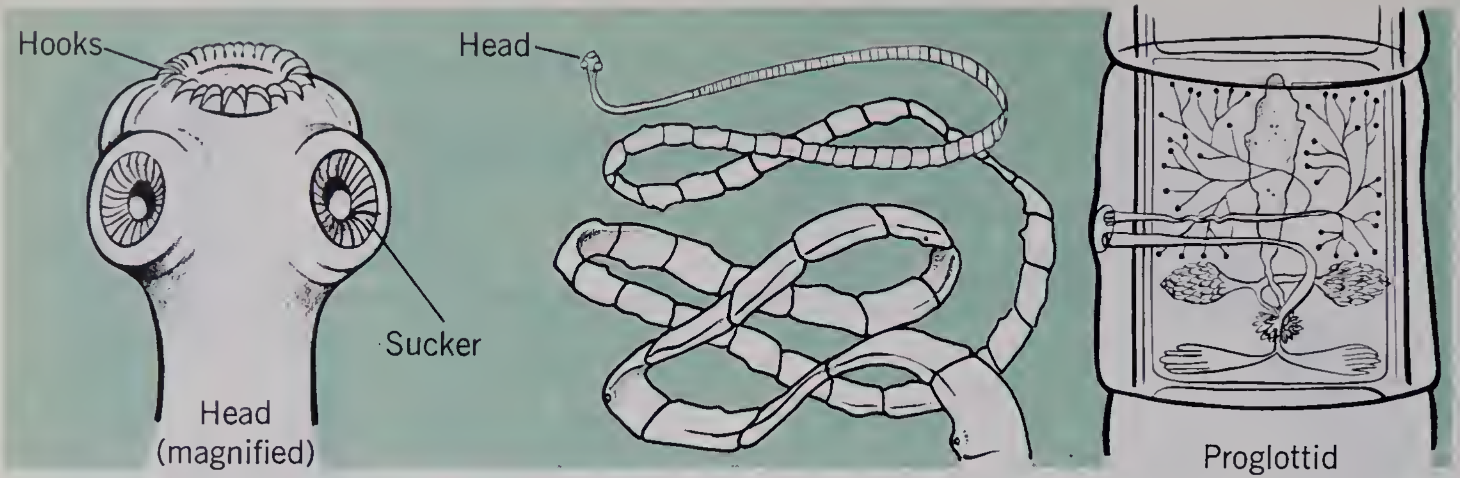
28-4 The life cycle of the sheep liver fluke.

the larvae pass through several stages during which they increase in number by asexual reproduction. They then leave the snail, crawl on blades of grass along the water, and form a *cyst,* or resting stage. If a sheep eats this cyst, the fluke enters the sheep's liver and the cycle starts again (Fig. 28–4).

Reactions of the host to the liver fluke may cause inflammation, swelling, general sickness, and irritability. In cows, milk production is reduced. Naturally, fluke infestation renders the liver unfit for human consumption. Other types of flukes may live in the blood, intestines, or lungs of animals. Many flukes are found on the external gills of fish and in cavities of other aquatic vertebrates, living on the epithelial tissue and blood of these hosts.

Although human fluke infestations are most common in the Orient, they are found in other areas too. Cuba has had several epidemics of human liver fluke. In some areas of the Gulf Coast, economic loss by liver-fluke infection of cows, pigs, and sheep has been severe. The best control of flukes is to eliminate one of the hosts in their life cycle. Usually this is a snail of some particular species.

The tapeworms. The tapeworms, the best known of the parasitic flatworms, are members of the ***Cestoda*** (*ses*-toh-da), a third class of Platyhelminthes. An adult tapeworm has a flat, ribbonlike body and is grayish white in color (Fig. 28–5). The adult tapeworm has no cilia. The knob-shaped head is equipped with suckers and in certain species with a ring of hooks. Below the slender neck a number of nearly square sections extend to a length of as much as 30 feet. The worm grows by adding new sections. Since new body sections, or ***proglottids*** (proh-*glaht*-ids), are formed at the head end, the oldest sections are on the posterior end. The proglottids are essentially masses of reproductive organs. Tapeworms are hermaphroditic, and eggs formed in a proglottid are fertilized there. When the eggs mature, the proglottids break off and are eliminated in the *feces* [*fee*-seez] (solid wastes eliminated from the intestines). Proglottids released in this way may be eaten by



28-5 The tapeworm can infect man only when he eats meat that is insufficiently cooked. Rigid inspection of meat has reduced the number of victims of this parasitic worm.

some animal such as a pig or cow. In the body of the new host, the eggs hatch into larvae, which burrow into the muscles and form cysts.

Tapeworms enter the human body in the cyst stage when the improperly cooked flesh of an infested animal is eaten. Each cyst contains a fully developed tapeworm head. In the human intestine the head is released from the cyst, attaches itself to the intestinal wall, and begins to grow.

Since a tapeworm robs the host of nourishment, the victim may lose weight and vitality. In recent years human tapeworm has been decreasing because of improved detection and treatment and because meat is inspected for tapeworm cysts.

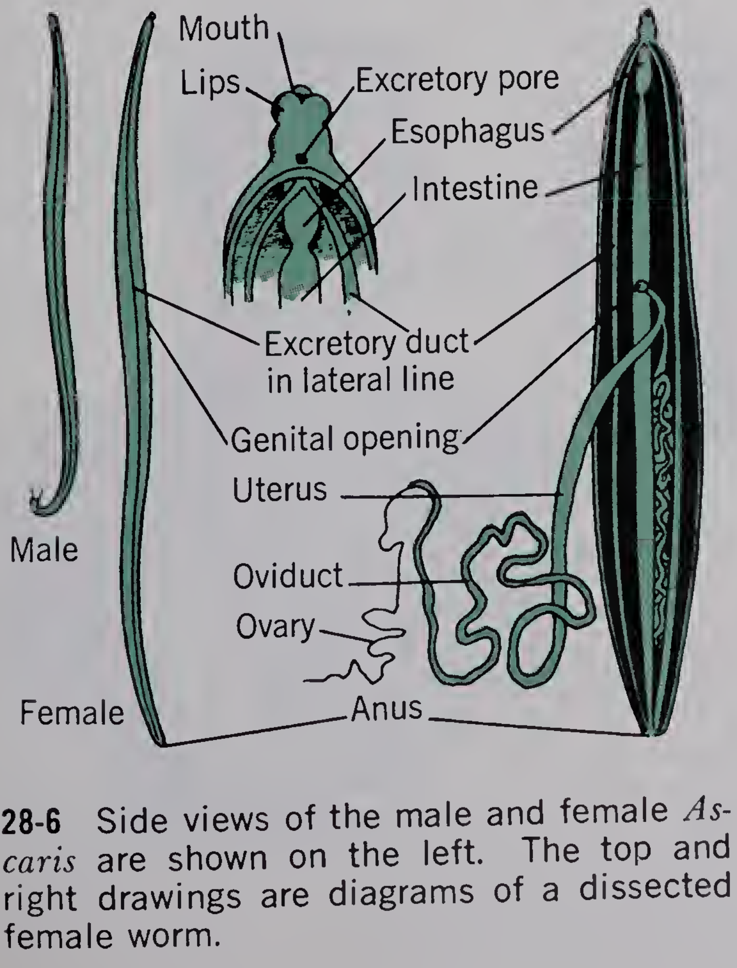
The roundworms. The phylum ***Nematoda*** (*nem*-a-toh-da) has only one class, also called ***Nematoda.*** The roundworms are long, slender, smooth worms, tapered on both ends. They may be as short as 1/125 inch or as long as four feet. They occur in soil, fresh water, salt water, and as parasites in plants and animals. The parasitic roundworms include the hookworm, trichina worm, pinworm, whipworm, *Ascaris* (*as*-ka-ris), and guinea worm. The nematodes are so abundant that —

> If all the matter in the universe except the nematodes were swept away, our world would still be dimly recognizable, and if, as disembodied spirits, we could then investigate it, we should find its mountains, hills, vales, rivers, lakes, and oceans represented by a film of nematodes. The location of towns would be decipherable, since for every massing of human beings there would be a corresponding massing of certain nematodes. Trees would still stand in ghostly rows representing our streets and highways. The location of the various plants and animals would still be decipherable, and, had we sufficient knowledge, in many cases even their species could be determined by an examination of their erstwhile nematode parasites. (Buchshaum, Ralph. *Animals Without Backbones.* The University of Chicago Press, 1948.)

When you consider that over one third of the human race, mostly in warm regions of the world, is infested with parasitic roundworms, their importance can hardly be overestimated. Harmless roundworms include the vinegar eel and the numerous beneficial soil nematodes.

Like the flatworms, the roundworms are bilaterally symmetrical and have three cell layers. They are, however, more complex than the flatworms. Their digestive system is a distinct tube with an opening at each end, housed in a long body which is also a tube (Fig. 28–6). This arrangement enables the animal to take in food through an anterior opening, the ***mouth,*** to digest it, and to remove the usable parts as it passes along the canal. Finally the undigested material is eliminated through a posterior opening, the ***anus.*** In the hydra, one opening was used for both the entrance of food and the elimination of undigested substances. The arrangement of a tube within a tube, however, makes possible the orderly progression of material through the digestive tract and greater efficiency in handling it.

Ascaris is a large roundworm which lives in the intestine of pigs, horses, and sometimes man. The females are larger than the males, and may reach a length of nearly 12 inches. *Ascaris* eggs enter the human in contaminated food or water. They do not hatch in the stomach, but begin to hatch in a few hours when inside the small intestine. Once hatched, the larvae bore into the intestinal wall to begin a ten-day journey through the body. This journey carries them into the blood stream and to the lungs. When they reach the lungs, these worms pass into the air passages, up to the throat, and are swallowed, once again passing into the digestive tube. There they grow to maturity in about two and a half months. After fertilization, the eggs are surrounded by a thick, rough shell and passed out through the genital pore of the female worm. A mature female lays about 200,000 eggs each day. These eggs pass out of the body of the host with the feces, and the cycle continues. *Ascaris* seems to be relatively harmless in man, although occasionally a large number of the adult worms twist together and block the intestine and cause death.



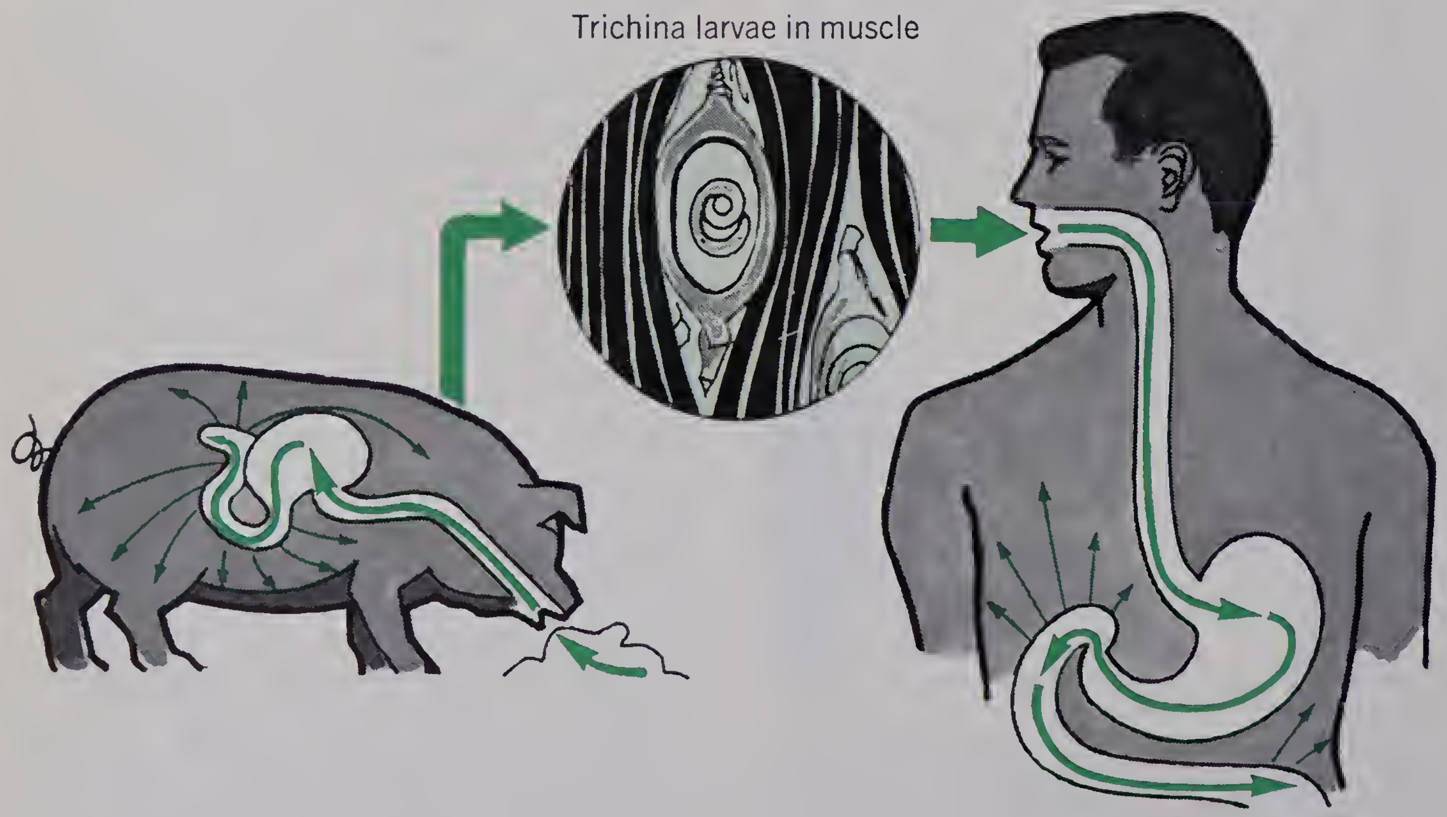
28-6 Side views of the male and female *Ascaris* are shown on the left. The top and right drawings are diagrams of a dissected female worm.

The *hookworm* of the southern states and all semitropical and tropical regions is a far more serious health menace. Larvae develop in the soil and enter the body by boring through the skin of the feet. Then they enter the blood vessels and travel through the heart to the vessels of the lungs. In the lungs they leave the blood vessels, enter the air passages, and eventually reach the windpipe and travel to the throat as *Ascaris* larvae do. They are swallowed and pass through the stomach to the intestine, where they attach themselves to the wall by means of jaws. In the intestine the larvae grow to adult worms, which suck blood from the vessels in the intestine wall.

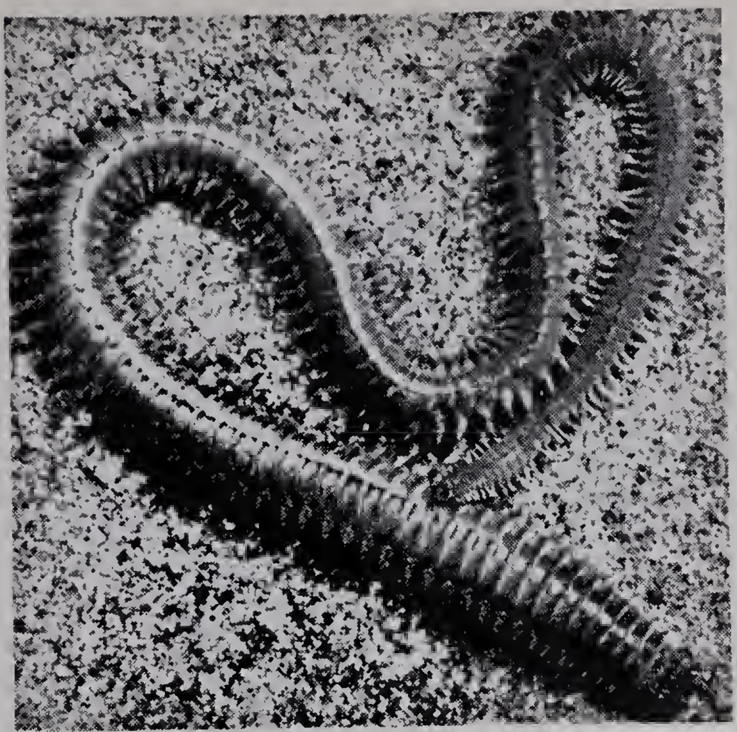
Loss of blood lowers the victim's vitality by producing anemia. A typical hookworm victim may be quite shiftless and his growth may be retarded, although the latter is not always true. In the intestine the worms reproduce, and the fertilized eggs leave in the fecal wastes. If these happen to lodge in warm moist soil, they develop into minute larvae which can enter through cracks in the feet and eventually return to the intestine. Thus, three factors are responsible for the spread of this disease: 1. improper disposal of sewage; 2. warm soil; and 3. the practice of going barefoot. Public health agencies have done a remarkable job in reducing the number of cases in the southern part of the United States.

The *trichina worm*, or *Trichinella*, is one of the most dangerous of the parasitic roundworms. This roundworm passes its first stage in the pig, dog, rat, or cat as a cyst in the muscles. If raw or uncooked scrap meat is fed to pigs, it may contain some of these cysts. In the intestine of a pig that eats infested scrap meat, these larvae develop into adult worms, mate, and produce microscopic larvae which pass into the blood stream and into muscles where they again form cysts. When a human eats undercooked, infested pork, the same thing occurs: the cysts are released and the larvae mature in the intestine (Fig. 28–7). Each worm emits into the blood stream about 1,500 young, which eventually form cysts in the muscles of the human. This disease is known as *trichinosis*. One method of preventing it is to feed hogs only cooked scrap meat. However, the best way to prevent this disease, as well as other parasitic worm infections, is to cook all meat as thoroughly as possible and thereby avoid any risk.

By this time the importance and widespread abundance of parasitic worms should be obvious to you. Each of these disease-producing worms is spread and picked up as a result of poor sanitary conditions. The eggs of the worms can be killed by proper sewage disposal. Proper inspection and thorough cooking of meat are measures that have reduced the spread of these parasites.



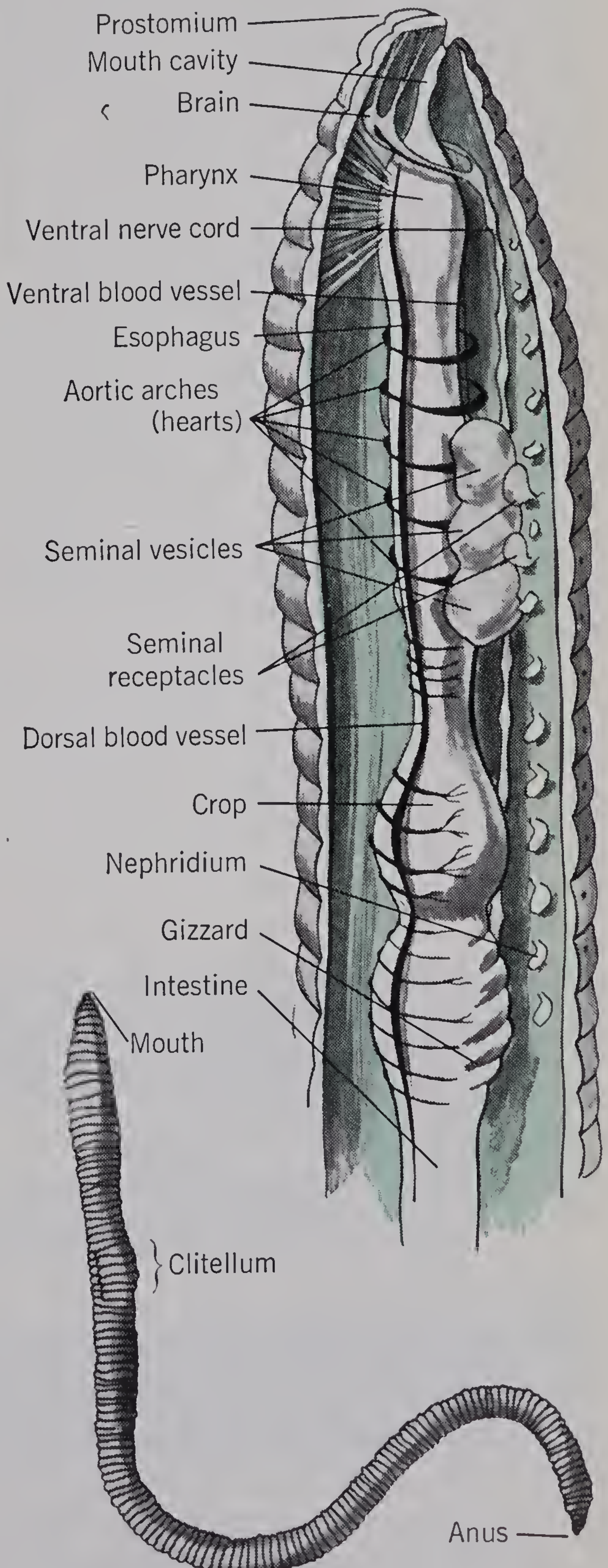
28-7 Diagram of the life cycle of the trichina worm.



28-8 The sandworm, *Nereis,* is one of the primitive annelids. (Walter Dawn)

The common earthworm. The segmented worms are the most advanced of the worms in body structure. They belong to the phylum ***Annelida,*** which is commonly divided into four classes (see Appendix). Most of the segmented worms live in salt water; some live in fresh water; and others, including the common earthworm, live in the soil. The annelids seem to be in a half-way spot between the simple protists and the highly complicated vertebrates. For this reason, and the fact that they are rather common, many biologists study them closely. They are considered typical invertebrates.

If you examine a common earthworm, you will notice immediately that its body consists of many segments. You will also see that the anterior end is more pointed and darker than the posterior. There is no separate head, nor are there any visible sense organs. The mouth is on the anterior end and is crescent-shaped, lying below a ***prostomium*** (proh-*stoh*-mee-um), which is a kind of upper lip. The vertical slit at the posterior end, the ***anus,*** is the opening of the intestine. The segments are often numbered by biologists, starting with the segment containing the mouth as num-


Prostomium
Mouth cavity
Brain
Pharynx
Ventral nerve cord
Ventral blood vessel
Esophagus
Aortic arches (hearts)
Seminal vesicles
Seminal receptacles
Dorsal blood vessel
Crop
Nephridium
Gizzard
Intestine
Mouth
Clitellum
Anus

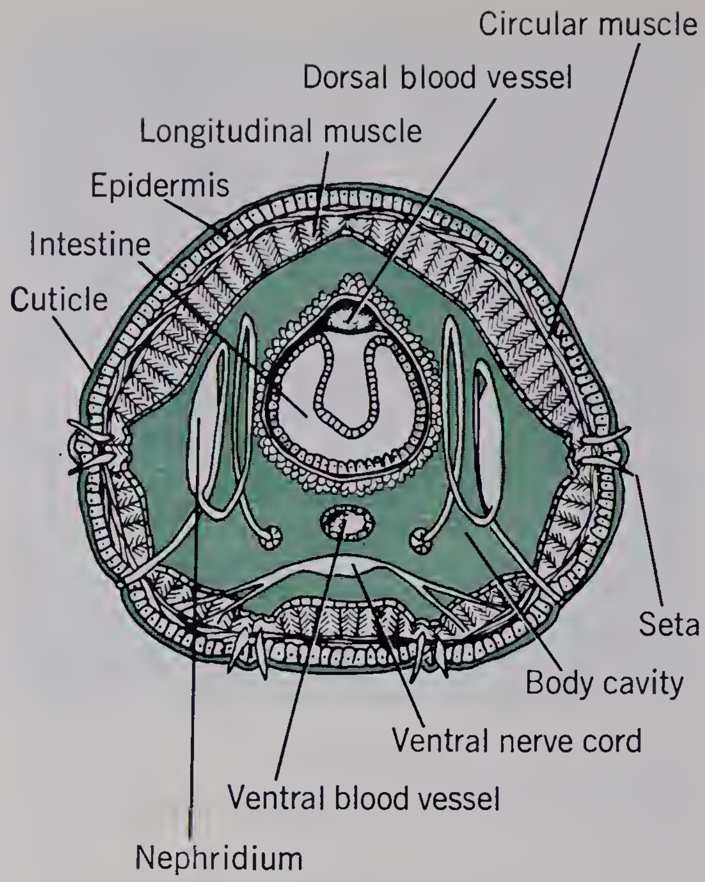
28-9 In this diagram of the earthworm the anterior portion is dissected to show the well-developed nervous and circulatory systems.

ber one, in order to locate definitely any special structure. On segments 32–37 there is a conspicuous swelling called the ***clitellum*** (kli-*tel*-um), which is involved in the animal's reproduction.

Four pairs of bristles, or ***setae*** (*see*-tee), project from the under surface and sides of each segment, except the first and the last. The setae assist the earthworm in movement and in clinging to the walls of its burrow, as those who hunt night crawlers can testify. The earthworm moves by burying its anterior setae into the soil, then shortening its body by a powerful series of ***longitudinal muscles*** which stretch from anterior to posterior ends. The worm then sinks its posterior setae into the soil, withdraws its anterior setae, and pushes forward by making itself longer. It does this by constricting the ***circular muscles,*** which are found around the body at each segment, so that the worm becomes thin and long.

As you study this animal you will notice that it consists not only of many cells, but of many kinds of specialized cells. These specialized cells are grouped together and each group performs the same function, so that they make up a *tissue.* The tissues that are grouped together to form larger structures which perform a definite function are *organs.* The earthworm is so arranged that a whole series of organs takes care of some fundamental body process. These are *systems.* The earthworm has well-developed *digestive, circulatory, excretory, nervous,* and *reproductive* systems.

Digestive system of the earthworm. Below the prostomium is the ***mouth*** of the earthworm. There are no jaws or teeth, but the animal sucks in soil containing food, by its muscular ***pharynx.*** The food particles then pass through a long ***esophagus*** into a round organ called the ***crop.*** This acts as a temporary storage place for food. From the crop the food is forced into a very muscular organ called the ***gizzard.*** There, by rhythmical contractions, the food is ground up by grains of sand rubbing the food particles. In the ***intestine,*** which stretches from segment 19 to the end of the worm, complete digestion takes place. Enzymes break down the food chemically, and the blood circulating through the intestine walls absorbs it.



28-10 This is a cross-sectional drawing of one of the abdominal segments of the earthworm.

The complex organs of the digestive system of the earthworm take up most of the anterior region. The earthworm consumes large quantities of soil, which contains organic matter. The useless inorganic matter passes through the system largely unchanged and is deposited on the surface of the ground in the form of *casts.* This method of feeding loosens the soil for air and water penetration and is of great importance to soil fertility.

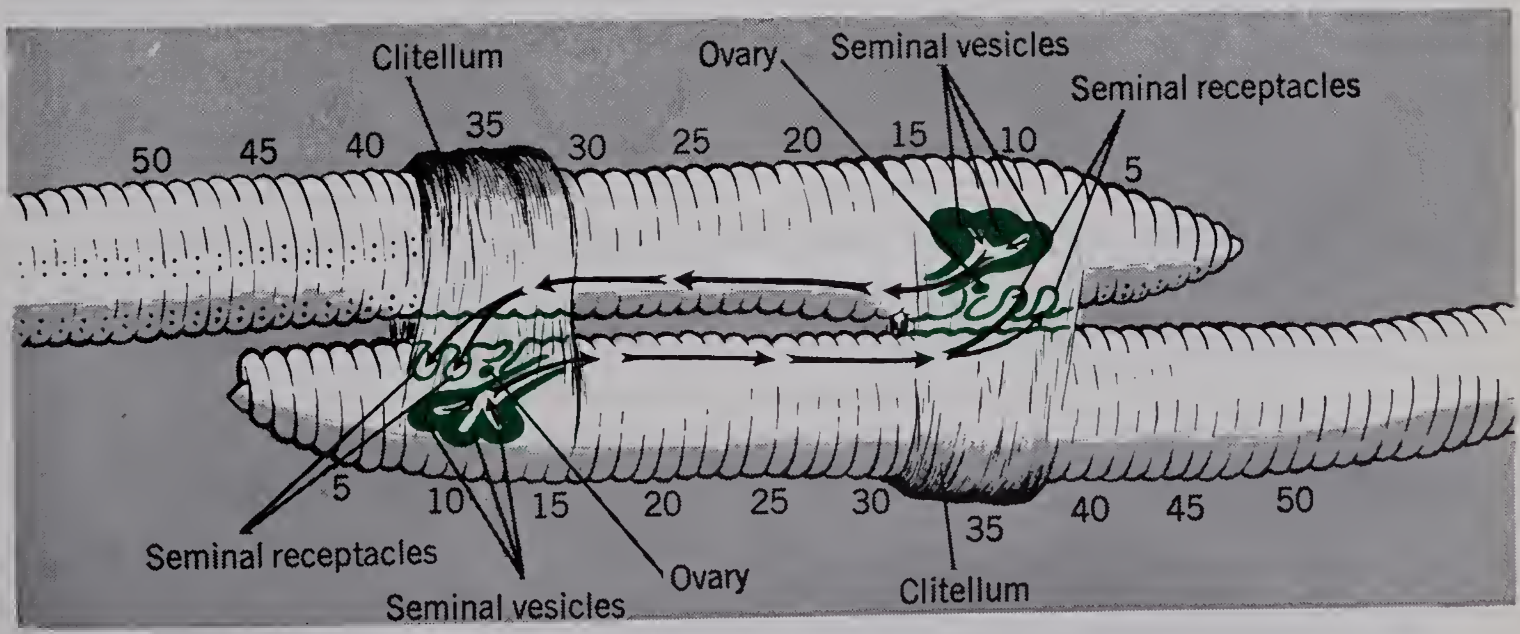
Circulatory system of the earthworm. As food is digested, the blood in the circulatory system picks it up for distribution to all the cells of the body. In the simpler animals we have studied so far, the digested food had only to diffuse a short distance to reach all the cells of the body. But in higher forms the distances are greater and more food material is needed by the many specialized and very active cells of the body. In these animals, therefore, we find a special transportation or distribution tissue — the circulating fluid called ***blood.***

The blood of the earthworm moves through a series of closed tubes, or vessels. It flows forward to the anterior end in a ***dorsal blood vessel*** and moves to the posterior end in a ***ventral blood vessel.*** Small tubes connect the dorsal and ventral vessels throughout the animal, except in segments 7–11. There the five connecting tubes are large and muscular. By alternate contraction and relaxation, they keep the blood flowing. They are not true hearts, but are called ***aortic*** (ay-*ort*-ik) ***arches.***

Respiration and excretion in the earthworm. The earthworm absorbs oxygen and gives off carbon dioxide through a thin skin. This skin is protected by a thin ***cuticle*** secreted by the epidermis and kept moist by a slimy mucus also produced by epidermal cells. A moist surface is necessary for oxygen to be absorbed and carbon dioxide to be given off. If the worm is dried by the sun it will die because the exchange of these gases can no longer take place.

Nitrogen-containing waste materials from cell activities are removed to the outside of the body by little tubes. There are two such structures, called ***nephridia,*** in each segment except the first three and the last. Each corresponds to a tiny kidney tubule in man.

Earthworm sensitivity. The nervous system coordinates the movements of the animal and sends impulses received from sense organs to certain parts of the body. There is a very small brain, or nerve center, in segment 3. From it run two nerves that form a connecting collar

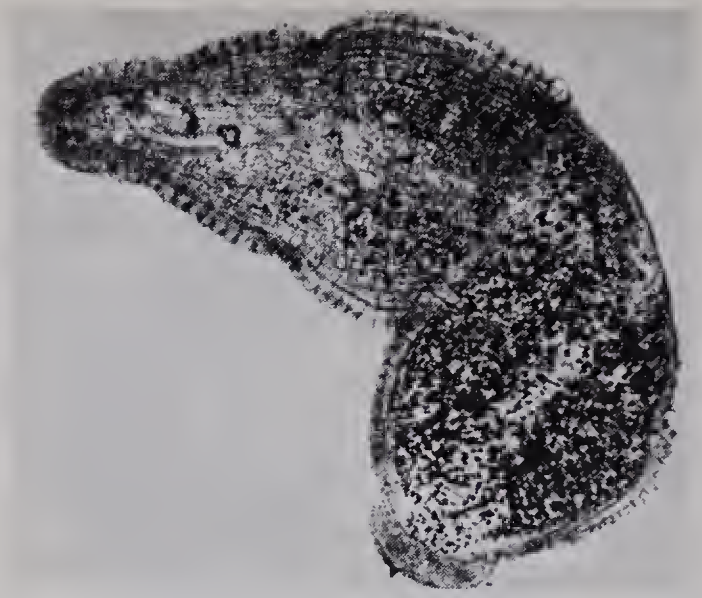


28-11 Although the earthworm has the reproductive organs of both sexes, it exchanges sperm with another animal as shown in this diagram. Sperm travel from the seminal vesicles of one worm to the seminal receptacles of the other.

around the pharynx and join to become a long ***ventral nerve cord.*** There are enlargements called ***ganglia,*** or nerve centers, in each segment. Three pairs of nerves in turn branch from each ganglion. The earthworm has no eyes or ears, but is nevertheless sensitive to light and sound. Certain cells in the skin are sensitive to these stimuli, and the impulses are carried rapidly to the muscles of the earthworm. Think how quickly they can react to a flash of light at night when you hunt them for tomorrow's fishing!

Reproduction in the earthworm is complex. Although earthworms are hermaphroditic, forming both eggs and sperm, the eggs of one worm can be fertilized only by sperm from another worm. In Fig. 28–11 you will see ***seminal vesicles,*** which extend from the testis sacs and store sperm produced by two pairs of testes within the sacs. The ***seminal receptacles*** store sperm from another worm.

Sperm from one worm travel from the seminal vesicles, through openings in segment 15, to the seminal receptacles of another worm, through openings in segments 9 and 10. Here they are stored until eggs are laid. When the eggs mature later they pass from the ovaries through openings in segment 14 and are deposited in a slime ring secreted by the clitellum. As this ring moves forward, sperm are released from the seminal receptacles and fertilization occurs. The slime ring slips from the body and becomes the cocoon in which the young worms develop.



28-12 The leech is another example of a segmented worm. (Walter Dawn)

The leech – another segmented worm. The *leech* (Fig. 28–12), also called a "bloodsucker," is an annelid found in streams and ponds. It is an external parasite on fish and other aquatic animals, but it may attach itself to your skin while you are swimming.

In sucking blood a leech attaches itself to some vertebrate by the posterior sucker, applies the anterior sucker to the skin, and makes a wound with the aid of little jaws inside the mouth. The salivary glands of the leech secrete a substance that prevents the clotting of blood while the worm is taking a meal. Leeches were used frequently for medicinal purposes in the Middle Ages and after, when it was thought beneficial to draw blood. Now the salivary substance is extracted and used to slow clotting after surgery.

IN CONCLUSION

This chapter has taken you through an interesting part of the animal kingdom. You have seen animals whose bodies are not limited to the tissue level as are the coelenterates, but are instead composed on the organ level of development.

The animals we have discussed in this chapter have three cell layers and bilateral symmetry. Some flatworms are free-living, while other degenerate forms live as parasites which depend on the body activities of the host organism. The roundworms are much more abundant than you had perhaps realized. They too include harmless, free-living forms as well as the parasitic hookworm, trichina worm, pinworm, whipworm, *Ascaris*, and guinea worm. The annelids, organized at the system level of development, include the common earthworm and the leech.

In the next chapter we shall study two groups of invertebrates that are related to the worms and at the same time to higher forms — the soft-bodied mollusks and the spiny-skinned echinoderms.

BIOLOGICALLY SPEAKING

Annelida
anterior
anus
aortic arch
asymmetrical
bilateral symmetry
Cestoda
circular muscle
clitellum
crop
cuticle
cyst
degeneration
dorsal
dorsal blood vessel
esophagus
eyespot
feces
ganglia
gizzard
hermaphroditic
intestine
larva
longitudinal muscle
longitudinal nerve
mesoderm
Nematoda
nephridia
pharynx
Platyhelminthes
posterior
proglottids
prostomium
radial symmetry
seminal receptacle
seminal vesicle
setae
spherical symmetry
transverse nerve
Trematoda
Turbellaria
uterus
ventral
ventral blood vessel
ventral nerve cord

QUESTIONS FOR REVIEW

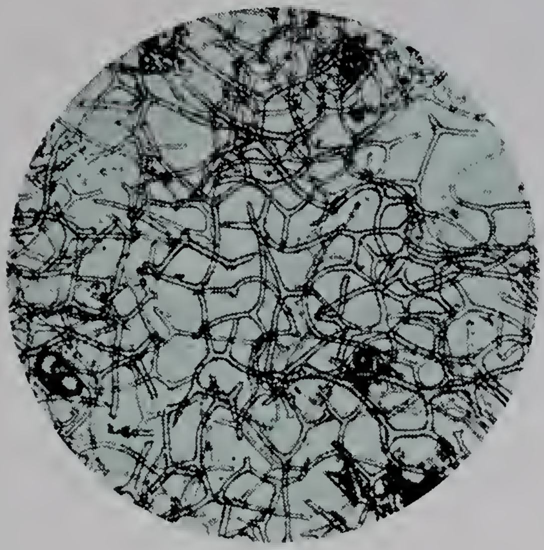
1. Name and define the types of symmetry. Give an example of each.
2. Discuss regeneration in the planarians.
3. What is the significance of the three layers of cells found in flatworms?
4. How does the planaria test its environment?
5. In what respects are the flatworms more complex than the sponges and coelenterates?
6. In what way does the tapeworm show degeneration?
7. Where are nematodes found?
8. How do the nematodes show an advance over the flatworms?
9. Describe the life cycle of *Ascaris*.
10. How does the trichina worm reach the human body?

11. How does the earthworm move?
12. Trace a particle of food through the digestive system of the earthworm, naming the organs through which it passes.

APPLYING PRINCIPLES AND CONCEPTS

1. Why do we classify the various worms into three separate phyla?
2. What advantage does bilateral symmetry have over spherical symmetry? What advantages does it have over radial symmetry?
3. Trace the path followed by *Ascaris* through the body by naming all the structures through which it passes. At what stages during its development are symptoms of disease most likely to be present?
4. Compare the advantages of the nervous system of the annelids over that of the planarians.
5. What measures are important to take in an effort to control parasitic worms?
6. Symptoms of tapeworm infestation usually include loss of weight and general tiredness. Account for these conditions.
7. Trichinosis can become a hopeless disease. Why is it almost impossible to treat?

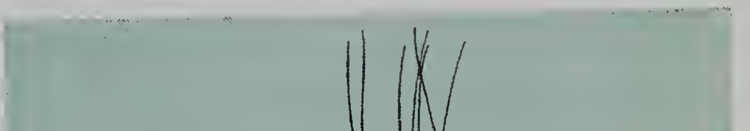
CHAPTER 29



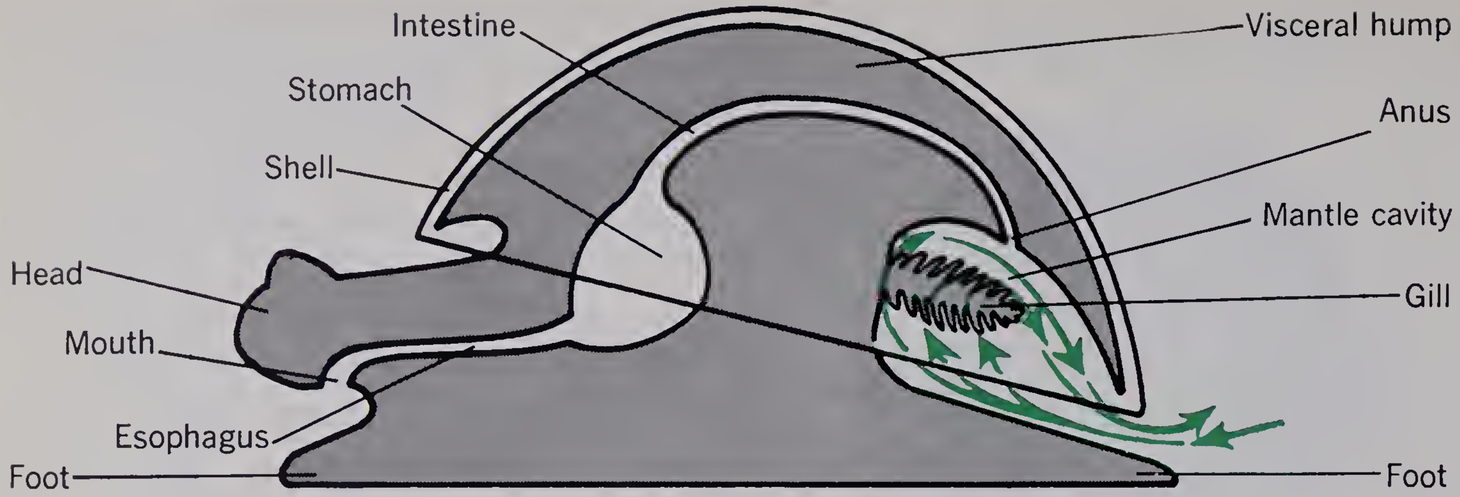
MOLLUSKS AND ECHINODERMS

Soft-bodied invertebrates. Although some ***mollusks*** are often called shellfish, they are really not fish at all. In fact many do not even have shells. Mollusks live in fresh water, marine, and terrestrial environments. Some are even adapted for life buried in sand or mud where the oxygen content may be too low for a more active animal. In abundance of species, the mollusks are surpassed only by the phylum that includes the insects. Although mollusks have been used for food, money, eating utensils, jewelry, buttons, dyes, tools, and weapons since earliest times, they have been of value to man in still another way. Since the shells of mollusks are hard, they or their imprints may remain in mud for thousands of years. These fossils may be used for comparison with present mollusks, giving us an opportunity to visualize the changes that have occurred in this form of life. Where layers of shells have accumulated in various strata of the earth, the geologist has been able to utilize them as a tool for dating as well as to reconstruct changes that have taken place in the earth's surface. Aggregations of certain shells are also used by engineers to determine the possibility of finding oil in various regions. What conclusion might you be able to draw if you found a large deposit of mollusk shells while hiking in the mountains?

The binding link of the mollusks. As you have already seen in Chapter 14, our system of classification is based on morphology, the organisms with the greatest resemblance being placed in the same species. Perhaps you have wondered why the clam, octopus, and garden snail are placed in the same phylum when they are apparently entirely different. In an attempt to place the many diverse forms of life into groups, we may theorize that organisms with



29-1 The trochophore larva is found in both mollusks and annelids.



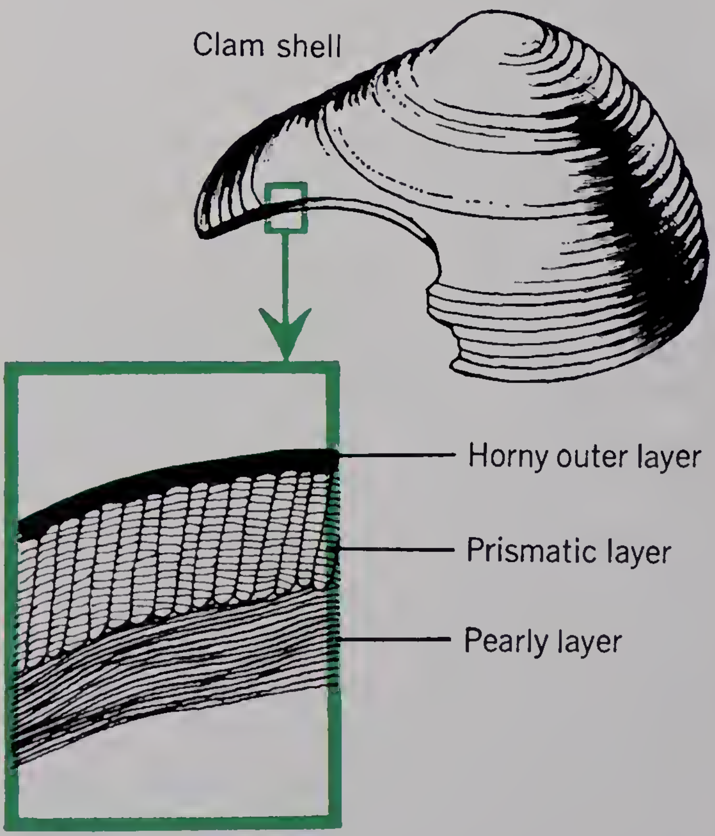
29-2 Although no living mollusk today looks like this drawing, the major characteristics of the phylum are shown. The arrows indicate direction of water flow in the mantle cavity.

similar larval development are related.

A link that ties the mollusks together as a group is the larval form called the ***trochophore*** (*trohk*-o-for). The trochophore has a tuft of elongated cilia at one end and a ciliated band around the equator (Fig. 29–1). The action of these cilia propel the larva through the water and bring food to the mouth. The terrestrial mollusks and most marine forms pass through the trochophore stage while confined to the egg capsule. The trochophore is also found in annelid development, and for this reason biologists consider the segmented worms and the mollusks to be related.

The general body plan. The body of an adult mollusk consists of a *head, foot,* and *visceral* (*vis*-e-ral) *hump* (Fig. 29–2). The ***visceral hump*** contains the digestive organs, excretory organs, and the heart. It is covered by a ***mantle,*** or thin membrane, which often secretes a shell by taking lime from the water. Where the mantle hangs down over the sides and rear of the animal, the ***mantle cavity*** is formed. The ***gills,*** which are the respiratory organs, are in this cavity. Undigested matter passes into the mantle cavity through the anus before being carried outside through the excurrent siphon.

Since a current of water must pass through the mantle cavity to bring in fresh oxygen and food as well as to carry away carbon dioxide and wastes, the mollusks with shells have a sanitation problem. The solution seems to be in the growth of tubes, or siphons. The ***incurrent siphon*** (or *ventral siphon*) takes water into the mantle cavity while the ***excurrent siphon*** (or *dorsal siphon*) takes water out of the mantle cavity.



29-3 The shells of the bivalve mollusks are composed of three distinct layers.

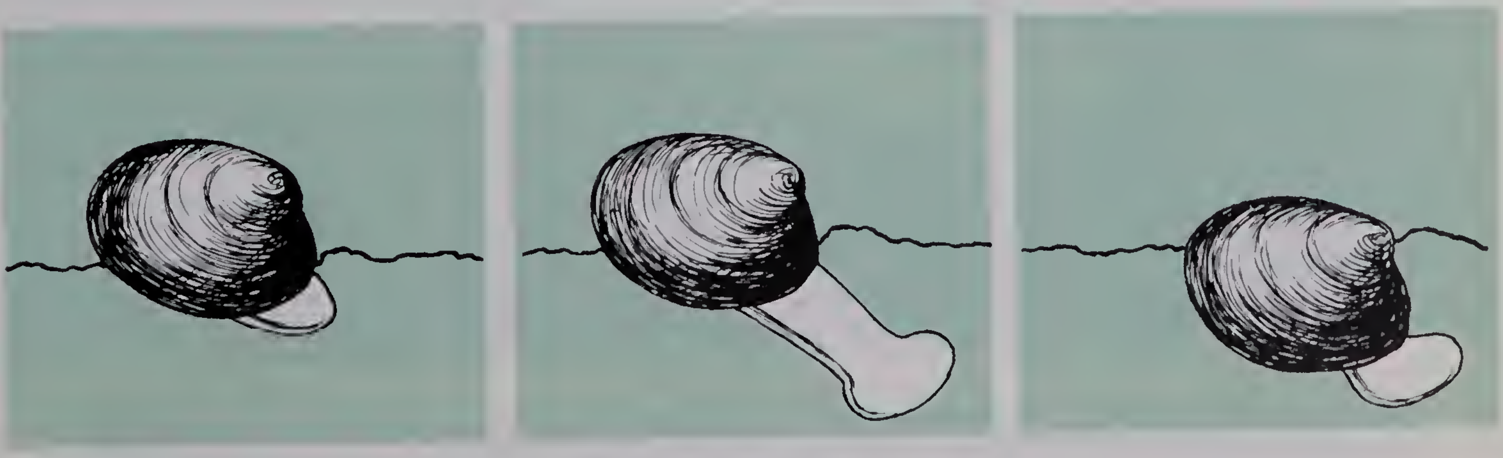
The major characteristic dividing this phylum into classes is the type of shell, if present. For the five classes into which we divide the mollusk phylum, see the Appendix.

Mollusks with two shells. The ***bivalves*** include the clams, oysters, scallops, and mussels. The shells, or ***valves,*** are connected by a hinge and are composed of three distinct layers. The inside ***pearly layer*** is smooth and glistening (Fig. 29–3). If a grain of sand or encysted parasitic worm becomes lodged in the mantle, this layer builds up around the particle and forms a pearl. The middle layer is composed of crystals of calcium carbonate and is named the ***prismatic layer.*** The outermost layer is very thin and may be peeled off when the shell dries. It resembles dried shellac or varnish and is called the ***horny outer layer.*** This substance forms the hinge and also protects the middle layer from being dissolved by small amounts of acid that may be in the water.

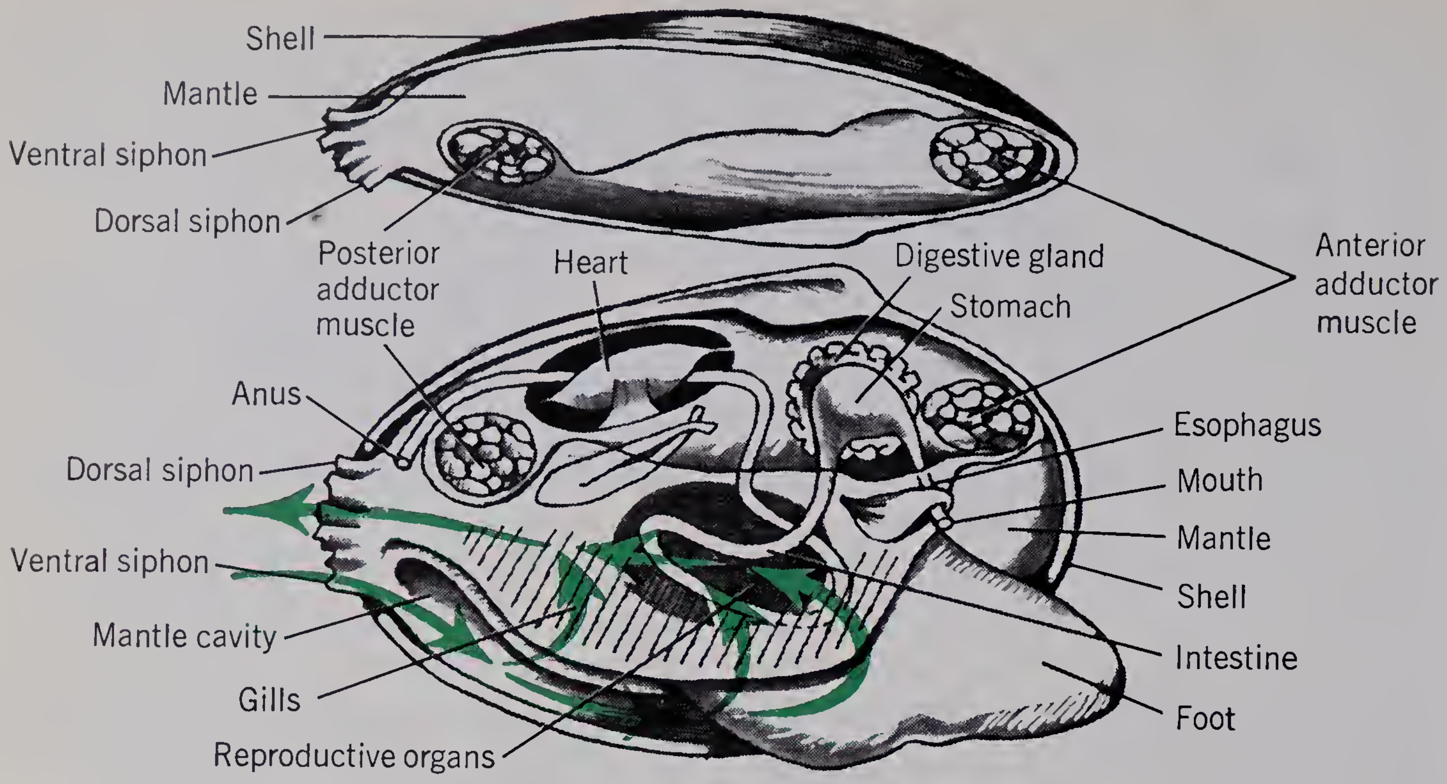
The major muscles in the bivalve are those holding the shells together. If you have ever pried apart the valves of an oyster or clam, you know their strength. The muscle of the foot is responsible for the scientific name of the group, Pelecypoda, which means "hatchet-footed" (Fig. 29–4). The foot extends into the sand and spreads out to form a hatchet-shaped anchor. Then, when the muscle of the foot contracts, the mollusk is pulled into the sand or mud. The clam is a rapid digger as some of you no doubt know!

As a clam is partially buried in the sand or mud, the shells remain partly open and the two siphons extend into the water. Water is brought into the mantle cavity by the incurrent siphon. The water passes up through the gills and then past the anus, where wastes are excreted. The excurrent siphon then carries the water out. As water passes over the gills, two processes occur: 1. oxygen diffuses in and carbon dioxide diffuses out; and 2. small particles of organic matter stick to a thin layer of mucus on the gills. Cilia on the surface of the gills carry the mucus up to the dorsal surface and then forward to the mouth. Animals that feed in this manner are said to be *mucus feeders*. Many marine worms also collect their food in a mucus trap. Mucus feeders are scavengers, taking advantage of dead and decaying organic matter as well as the numerous microscopic protists that settle to the bottom.

Bivalves have a well-developed nervous system with several large ganglia. The edges of the mantle contain sensory cells which are sensitive to contact and light.



29-4 Note how its hatchet-shaped foot aids the clam in digging into the sand.

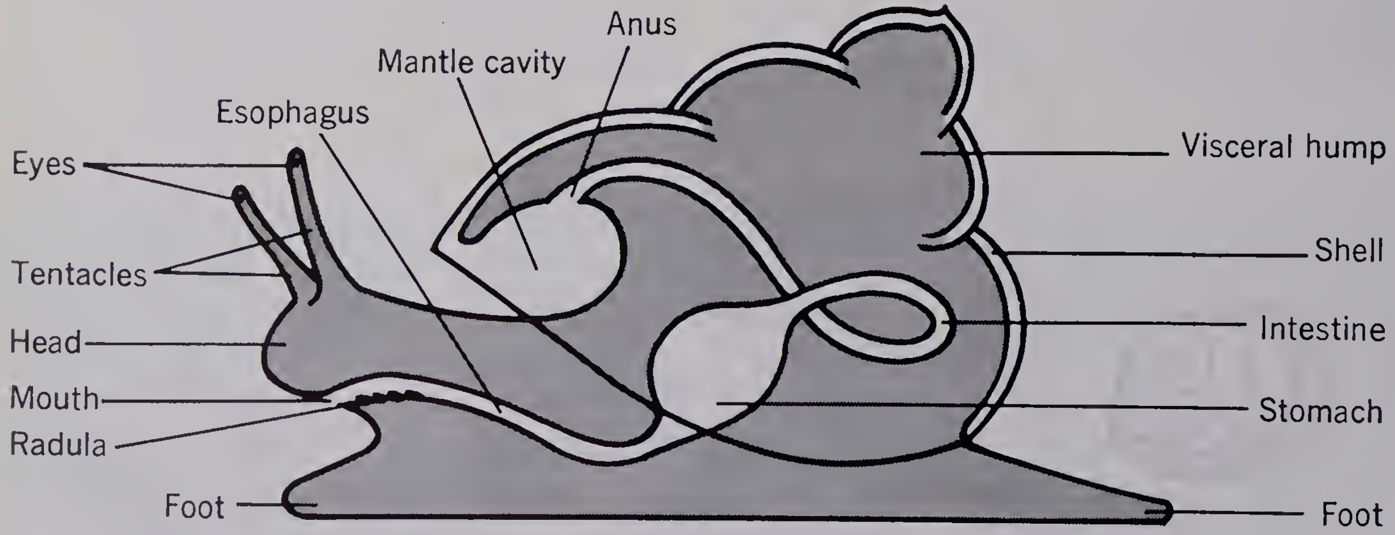

Shell
Mantle
Ventral siphon
Dorsal siphon
Posterior adductor muscle
Heart
Digestive gland
Stomach
Anterior adductor muscle
Anus
Dorsal siphon
Ventral siphon
Mantle cavity
Gills
Reproductive organs
Esophagus
Mouth
Mantle
Shell
Intestine
Foot

29-5 In this diagram of a dissected clam, the arrows indicate the direction of water flow.

Clams, oysters, scallops, and mussels are edible bivalves. Since they feed on microscopic organisms, some of which are poisonous to man, and since they are often eaten raw, care must be used in gathering them. Naturally mollusks are not edible when their digestive tracts contain poisonous protists.

In the Indo-Pacific region, an interesting relationship occurs between one-celled algae and the giant clam, which may be a yard and a half long. Immense numbers of these algae live in the mantle of the clam, giving it a green color. The algae manufacture starch and oils and are often contained in ameboid cells which carry them to the digestive area of the clam.

Mollusks with one shell. Common univalves, or *gastropods,* include land and water snails, conches, and abalones. If a scientist were trying to reconstruct the


Anus
Mantle cavity
Esophagus
Eyes
Tentacles
Head
Mouth
Radula
Foot
Visceral hump
Shell
Intestine
Stomach
Foot

29-6 Compare the structure of the land snail shown here with the generalized mollusk in Fig. 29-2, and with the clam in Fig. 29-5. In what ways does it differ and in what ways is it similar?

way the snail developed from a hypothetical ancestor, he would compare the two. Try to picture the following changes in the generalized mollusk in Fig. 29–2: rotate the visceral hump halfway around; remove the gills; put some spirals in the shell — it would now resemble a snail. The land snail is a good mollusk to study for it is easily obtained and moves around freely while being observed. See if you can find the prominent structures on a land snail in Fig. 29–6.

The terrestrial snail moves at a "snail's pace" of about ten feet per hour. The flat, muscular foot secretes slime on which the snail travels in rhythmic waves. The eyes of land snails are on the tips of two tentacles. When touched, the snail draws in these tentacles, somewhat as the toe of a stocking vanishes when you turn it inside out.

The slug looks like a snail that has lost its shell. It comes out at night, leaving trails of slime wherever it goes. Slugs eat plant leaves and cause considerable damage, as do snails.

The fresh-water snails in a school aquarium are excellent for observing the feeding mechanism of a gastropod. Here you will see the mouth of the animal open and a tonguelike structure scrape the glass of the aquarium. This structure is named the ***radula*** (*rad*-uh-la), which literally means "scraper." The radula is like a file, and actually files algae from the glass sides of the aquarium. Now you can understand how garden snails and slugs, also equipped with radulas, can cause such damage to your plants.

"Head-foot" mollusks. The ***cephalopods*** (*sef*-a-luh-pahds) include the octopus, squid, cuttlefish, and chambered

29-7 The cuttlefish is one of the most highly developed of the invertebrates. The shell of the animal is internal and consists of a calcified plate. (Annan Photo Features)

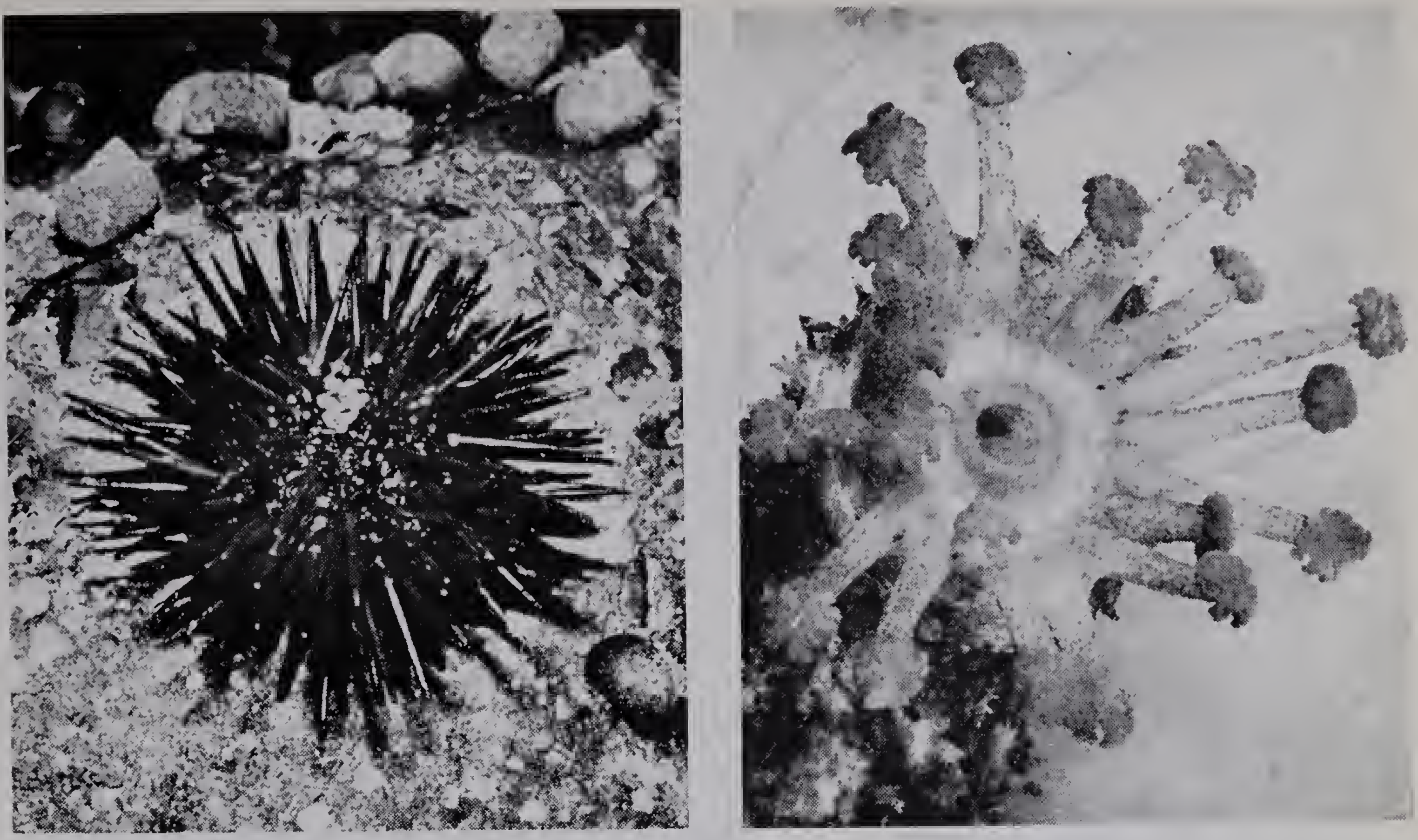
29-8 The octopus is a cephalopod without a shell and with extremely well-developed eyes. It moves by pulling itself over rocks with its tentacles. (Annan Photo Features)

nautilus. The octopus has no shell; the nautilus has an external shell; and the squid and the cuttlefish have an internal shell. The giant squid is probably the largest of all invertebrates, sometimes reaching a length of 55 feet and a weight of two tons. The octopus has the worst reputation, probably undeserved. As a rule they are timid creatures. The largest species has a body not more than one foot long, but its slender arms may reach 16 feet in length. This species lives along the Pacific Coast. There are about 400 species of cephalopods today. When compared with the over 10,000 fossil forms, one might wonder if they are to become extinct, as have many other organisms.

The spiny-skinned invertebrates. The starfish, brittle star, sea urchin, and sand dollar are common members of the phylum ***Echinodermata*** (i-*ky*-nuh-derm-a-ta). They have a hard, radially symmetrical body covered with spines. The spines may be long, as in the sea urchin, or very short, as in the sand dollar. All the echinoderms are restricted to the marine environment. They have been collected from the shallowest tide pools to great ocean depths. The five classes are listed in the Appendix.

Although the radial symmetry of the echinoderms is unlike that in any other animal phylum, many biologists would place them near the lower chordates because of their larval development. The free-swimming *dipleurula* larva is ciliated and contains a mouth, a digestive tract, and an anus (Fig. 29–10). After swimming about for a period of time, the larva settles on a solid object and gradually changes into the adult form.

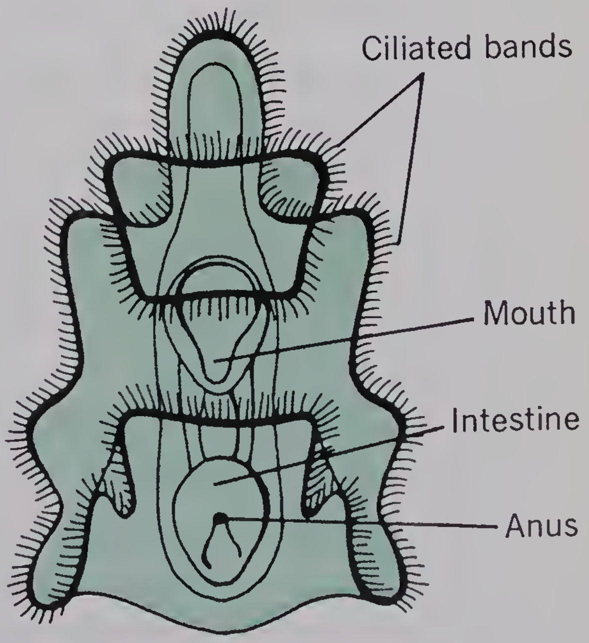
The characteristics of the phylum can be observed in one of its most familiar members — the starfish. In spite of its name, the starfish is not a fish, but possesses five (or rarely six) rays, which radiate from a central disk. In a groove on the lower side of each movable ray are two rows of ***tube feet*** (Fig. 29–11). These are part of a ***water-vascular sys-***



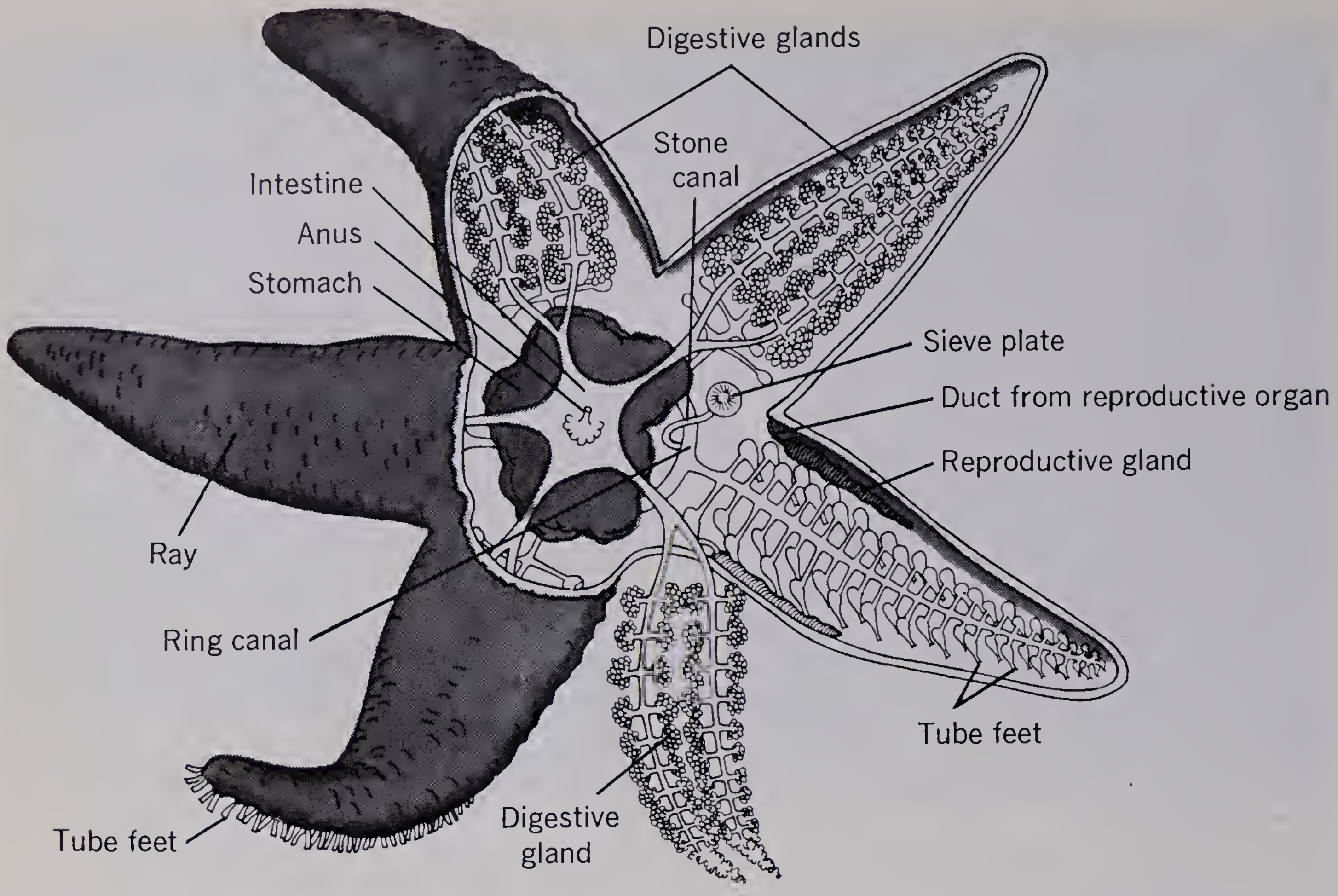
29-9 The spiny echinoderm on the left is a sea urchin. The mouth of a sea cucumber is shown on the right. (Left: Walter Dawn; right: Hermes from National Audubon Society)

tem. The tube feet are connected to canals which lead through each ray to a circular canal in the central disk. This ***ring canal*** has an opening to the surface, the ***sieve plate,*** on the dorsal side. When the starfish presses its tube feet against an object and forces water out of the canals, the feet firmly grip by means of suction. Return of water to the canals releases the grip.

The starfish uses its water-vascular system to open the shells of clams and oysters, its principal food. The body arches over the prey with the rays bent downward. The shells of the clam or oyster are gripped firmly by the tube feet, and a steady pull is exerted at the same time. The starfish secretes a substance that paralyzes the clam or oyster. After a while the shell muscles of the prey tire, and the halves of the shell separate. At this point the starfish pushes its stomach out from a small opening in the center of the lower side. The stomach, turned inside out, enters the shell and digests the body of the clam or oyster, leaving only the shell. Although starfish have extensive skeletons, they are quite flexible and can bend very easily around an oyster.



29-10 This dipleurula larva of an echinoderm is similar to that of some of the lower chordates.



29-11 This is the dorsal view of a dissected starfish.

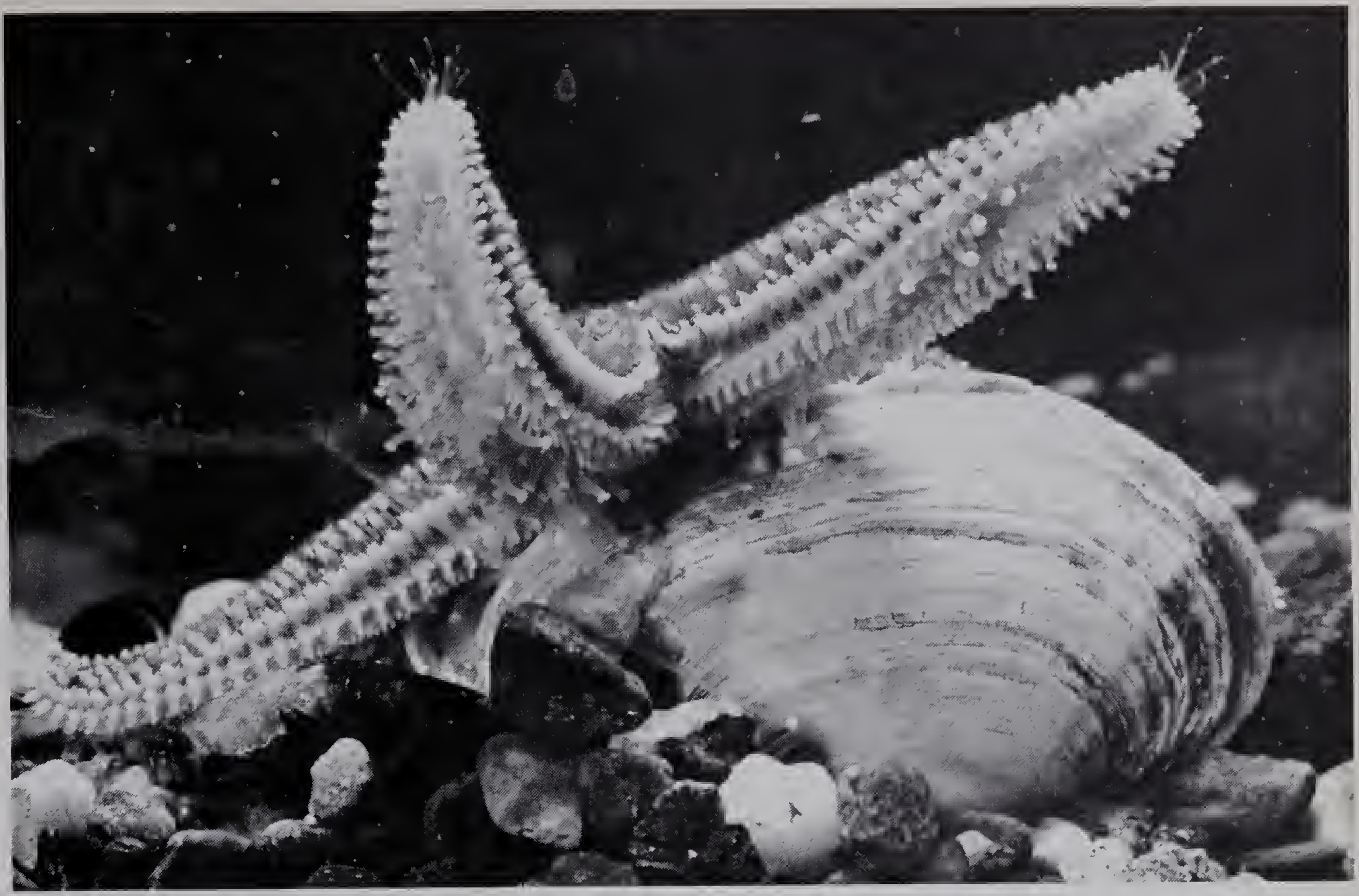
Food passes from the stomach of the starfish into digestive glands in which digestion is completed. Some undigested matter passes out through the mouth. Above the stomach is a short intestine which ends in the anus on the dorsal surface.

The starfish are either male or female, and the reproductive organs lead to the outside by small ducts. During the reproductive season eggs and sperm are shed to the outside, where fertilization takes place in the water. The female starfish may produce as many as 200 million eggs in a season.

Oystermen are on constant lookout for starfish in clam or oyster beds. An active, adult starfish can destroy eight to twelve oysters a day. People used to tear starfish to pieces, thinking that they were destroying the pests. Actually they were multiplying their troubles, for a starfish ray, with a portion of the central disk, can regenerate and become an entire new starfish.

Although the echinoderms are not an economically important food, some are consumed. Sea urchins are sometimes collected on beaches and their eggs eaten. In the Orient, sea cucumbers are collected, dried, and sold as *bêche-de-mer* or trepang (tri-*pan*) for use in soup.

What is a phylogenetic tree? Before proceeding with the largest invertebrate phylum, the Arthropoda, let us look for some regularities which may be useful in understanding the course of animal evolution. Figure 29–13 is a diagrammatic representation of how a taxonomist might fit shreds of evidence together to imagine how animal diversity evolved. It is called a ***phylogenetic tree.*** There are many such schemes, and they are used to point out relationships based on incomplete fossil records,

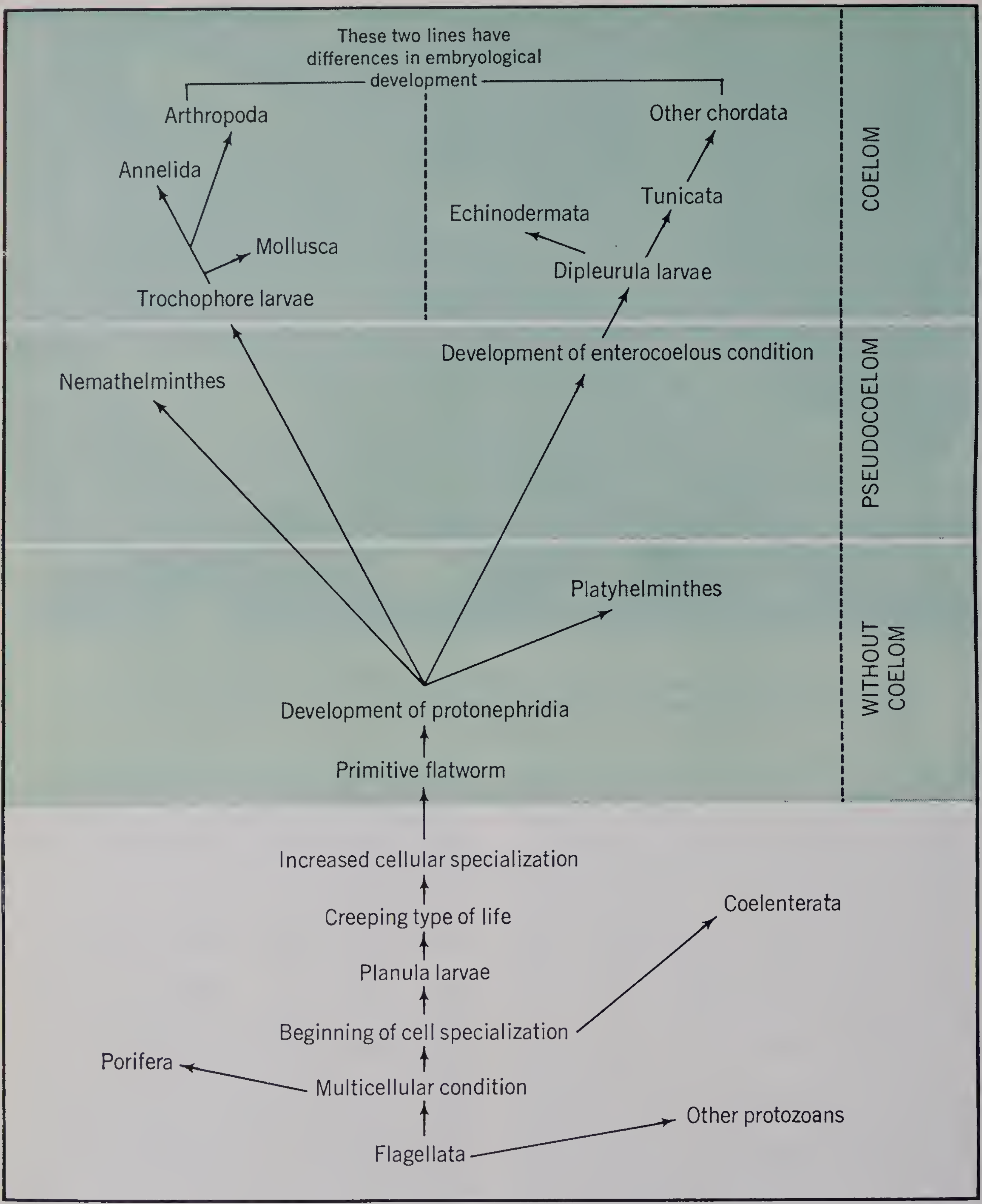


29-12 A starfish shown in the process of paralyzing and digesting a clam. Note the extended stomach. (Charles Walcott)

morphological similarities of existing animals (both larval and adult), and imagination. When we examine the larval forms of the mollusks, for example, we find that they are very similar. It can be theorized, then, that they evolved from a primitive ancestor which was like the larval form. No one can say for sure, nor can anyone disprove it. Furthermore, if we find that annelids also have a larval form very similar to that of the mollusks, we can postulate that these two apparently different phyla developed from a trochophore-type ancestor.

You will notice that in Fig. 29–13 there seems to be one main direction until structures called *protonephridia* (proh-toh-ne-*frid*-ee-a) develop. A protonephron is a very primitive type of kidney. According to the diagram, then, all the organisms beyond this point possess a protonephron. This is true, but in the development of many animals the protonephron undergoes complicated changes before the adult stage is reached.

One of the characteristics considered in grouping animals is the type of body cavity, or ***coelom*** (*see*-lom), present in the adult. Among the bilaterally symmetrical organisms, the flatworms do not possess a body cavity between the internal organs and the body wall (Fig. 28–2). As the body of an animal increases in size; a solid structure such as is found in the flatworms would not be physiologically efficient. A fluid-filled cavity allows for looped intestines and aids in circulation of food and oxygen, as well as waste removal. For this reason, the majority of animals have a coelom. The coelom develops within the mesoderm of the embryo and has a lining of specialized covering cells. This lining surrounds the inter-


These two lines have differences in embryological development
Arthropoda
Other chordata
COELOM
Annelida
Tunicata
Echinodermata
Mollusca
Dipleurula larvae
Trochophore larvae
Development of enterocoelous condition
Nemathelminthes
PSEUDOCOELOM
Platyhelminthes
WITHOUT COELOM
Development of protonephridia
Primitive flatworm
Increased cellular specialization
Creeping type of life
Coelenterata
Planula larvae
Beginning of cell specialization
Porifera
Multicellular condition
Other protozoans
Flagellata

29-13 This phylogenetic tree shows a possible relationship of the various groups of invertebrates, as well as their supposed relationship to the protists.

nal organs and covers the inner surface of the body wall. It forms a membrane-like structure that suspends the intestine within the coelom.

Between the animals with a coelom and those without, in our phylogenetic tree, are the animals possessing a *pseudocoel* (*sood*-oh-seel), or false coelom. This cavity is not lined with specialized covering cells and therefore has no suspending membrane. The internal organs are free within the cavity.

IN CONCLUSION

In the study of the mollusks and echinoderms, you have investigated some of the most prominent inhabitants of the seas and tide pools. Although the mollusks live in marine, fresh-water, and terrestrial environments, the echinoderms are the only major, exclusively marine phylum.

You have seen some of the ways in which data are gathered and used to form hypotheses about the relationships and evolution of many diverse forms of life. Observations and imagination are important biological tools.

In the chapters to follow we shall continue the study of invertebrates with a phylum, which, if numbers indicate significance, is the most important of invertebrate groups. Here are insects, spiders, lobsters, and many others.

BIOLOGICALLY SPEAKING

bivalves
cephalopod
coelom
Echinodermata
excurrent siphon
gastropod
gill
horny outer layer
incurrent siphon
mantle
mantle cavity
mollusks
pearly layer
phylogenetic tree
prismatic layer
radula
ring canal
sieve plate
tube foot
trochophore
visceral hump
water-vascular system
valves

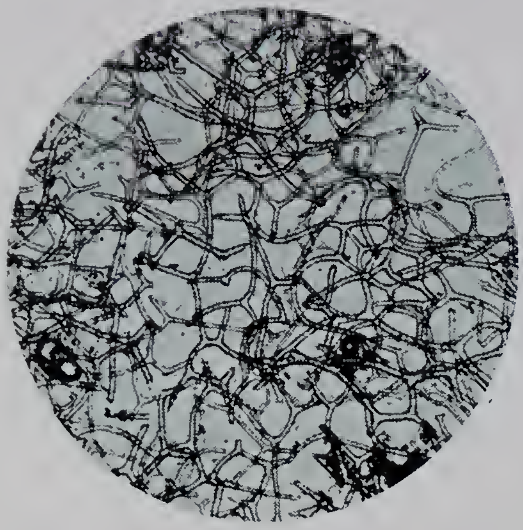
QUESTIONS FOR REVIEW

1. What characteristics of the mollusks divide the phylum into classes?
2. What are the three characteristics all mollusks have in common?
3. Trace a particle of food from the outside of the clam to the digestive gland, naming the organs through which it passes.
4. What layers are formed in the making of the shell?
5. How does the oyster form a pearl in its shell?
6. In what ways do the cephalopods differ from the gastropods?
7. What characteristics of the echinoderms distinguish them from other invertebrate animals?
8. Describe the movement of the starfish.
9. How does the water-vascular system assist the starfish in eating?

APPLYING PRINCIPLES AND CONCEPTS

1. What structural similarities relate the mollusks and the annelids?
2. What property of mollusks makes them of help to the geologist?
3. In what ways have the mollusks been of value to man? In what ways have they been a pest?
4. Shells of mollusks are frequently ground up and used as fertilizer. What are some of the substances these shells add to the soil?
5. What data are used in making a phylogenetic tree?

CHAPTER 30



THE ARTHROPODS

Arthropod characteristics. From the standpoint of numbers the arthropods are considered the most successful group of animals. The phylum ***Arthropoda*** includes the familiar insects, spiders, centipedes, millipedes, crayfish, crabs, and lobsters. Arthropods are found everywhere. They serve as food for man and compete with him for it. Many live as parasites in or on other organisms, and some transmit disease.

To the casual observer the graceful butterfly has little in common with the crayfish lurking under a rock in a stream. But careful study of these quite different animals will show that they have much in common. The characteristics that make the butterfly similar in structure to the crayfish also relate these creatures to spiders, scorpions, and centipedes. All members of the phylum Arthropoda are similar in having the following characteristics:

1. Jointed ***appendages,*** which include legs and other body outgrowths. This characteristic gives the phylum its name, which means "jointed feet."
2. A hard external skeleton, or ***exoskeleton,*** composed of a substance called ***chitin*** (*kyt*-n), instead of the internal support we have.
3. A segmented body, which refers to the distinct divisions of the exoskeleton.
4. A dorsal heart; that is, one that is located above the digestive system.
5. A ventral nervous system, with the main nerves below the digestive system.
6. Muscles in groups.
7. Distinct jaws.

The development of the phylum. The fact that the arthropod body is divided into segments suggests a relationship to

COMPARISON OF ARTHROPODS AND ANNELIDS

Arthropod Characteristics	*Annelid Characteristics*
Legs divided into movable joints	No legs
Hard chitinous exoskeleton	Flexible cuticle
Fewer segments, more highly specialized	Many segments alike
Dorsal heart	Dorsal heart
Ventral nervous system with specialized sensory receptors such as eyes and antennae	Ventral nervous system but sensory receptors simple
Muscles in groups	Muscles in sheets

the annelids. This relationship is often expressed when biologists refer to the "annelid-arthropod" line of development (see the phylogenetic tree shown on page 408). When you compare characteristics of the arthropods and annelids, in the table on page 410, you may understand why the arthropods were able to become more successful than the annelids. The increased complexity of their sense organs allows for coordinated responses to their environments. The groups of muscles and jointed legs allow for more coordinated movement in the search for food and in escape from enemies. As you see, the arthropod characteristics permit greater efficiency and adaptability to the environment.

The development of the hard exoskeleton is a protective advantage over the soft cuticle of the worm. It may seem strange to find the skeleton on the outside of the body of an animal. But whether they are internal or external, skeletons have the same function. They give the body form, protect delicate internal organs, and aid in motion by serving as attachments for muscles. Unlike an internal skeleton, however, an exoskeleton is a size-limiting factor. A large exoskeleton with the powerful internal muscles required to move it would crush the animal under its own weight. Flying insects, for example, could never attain the size of birds because their exoskeletons would be too heavy to be supported by wings. Growth in the size of an organism with

CLASSES OF ARTHROPODS

Class	*Body Divisions*	*Appendages*	*Breathing*	*Examples*
CRUSTACEA	2 — cephalothorax, abdomen	5 pairs or more	Gills	Lobster, crab, water-flea, sowbug, crayfish
CHILOPODA	Head and numerous body segments	1 pair on each segment except first one behind head and last 2	Tracheae	Centipede
DIPLOPODA	Head and numerous body segments	2 pairs of legs on each body segment	Tracheae	Millepede
ARACHNIDA	2 — cephalothorax, abdomen	4 pairs of legs	Tracheae and book lungs	Spider, mite, tick, scorpion
INSECTA	3 — head, thorax, abdomen	3 pairs of legs; usually 1 or 2 pairs of wings	Tracheae	Grasshopper, butterfly, bee, dragonfly, moth, beetle

an exoskeleton can only take place by ***molting***, whereby the old skeleton is shed and a new one is formed. This process will be discussed in detail later in this chapter.

Diversity among the arthropods. In the classification of the arthropods, such widely varied forms as butterflies and crayfish, spiders and centipedes are segregated into classes. This large phylum is commonly divided into five classes, as shown in the table on page 411.

Each of these classes has all the fundamental characteristics of arthropods, and, in addition, certain characteristics of the class to which it belongs. For example, the ***Crustacea*** (kruh-*stay*-shuh) have two pairs of antennae, or "feelers," on the front of the body, two distinct body regions, five pairs of legs, and a chitinous exoskeleton which contains lime, and often structures called ***gills*** for respiration. The ***Insecta***, on the other hand, have one pair of antennae, a body composed of three parts, three pairs of legs, often two pairs of wings, and an exoskeleton composed of chitin lacking lime. They respire by means of air tubes called ***tracheae*** (*tray*-kee-ee).

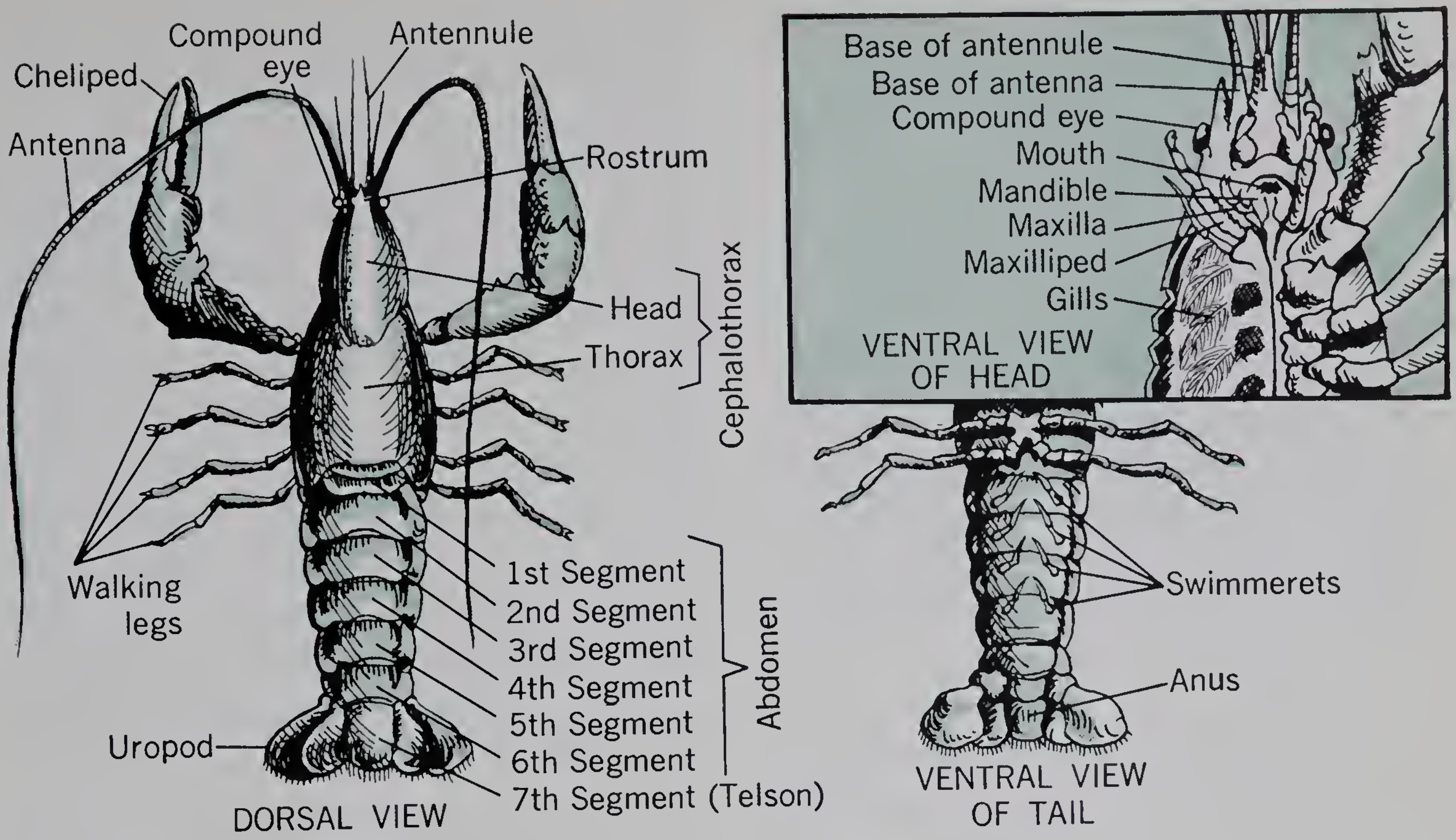
The arthropods show a great advance over other animals already studied. Worms, especially the earthworm, show a high degree of specialization of body parts and the presence of specialized internal organs. In our study of the Crustacea as typical arthropods, we shall deal with animals such as the crayfish, lobster, and crab, which are adapted for aquatic life. Division of labor among their various organs is carried to an even higher point than we found in the earthworm. All of this specialization has resulted in an efficient animal, very well-adapted to our present world. The segmented body is, of course, common to both the arthropods and the annelids. The ventral nervous system first appeared in the worms.

The crayfish – a large fresh-water crustacean. Scientists often use the crayfish to observe the features of the class Crustacea because the crayfish is large and easily obtained; it can be found in nearly all rivers, lakes, and streams that contain lime, which is used in hardening its exoskeleton.

The body is divided into two regions. The first of these, called the ***cephalothorax*** (*sef*-al-oh-*thor*-aks), includes the head and a second region, the *thorax*. These are separate in many arthropods. The ***abdomen***, composed of seven movable segments, is posterior to the cephalothorax. Vital parts of the cephalothorax are protected by a shield called the ***carapace*** (*kar*-a-pays), which extends forward as a beak, called the ***rostrum***. On either side of the rostrum are the eyes. These are set on short movable stalks and are composed of numerous lenses. For this reason they are called ***compound eyes***.

Specialization in crayfish appendages. The most anterior appendages of the crayfish are the ***antennules***, which contain the hearing and equilibrium apparatus. The large ***antennae*** attach just posterior to the antennules. They function as organs of touch, taste, and smell. The next appendages are the ***mandibles***, or true jaws, which crush and chew food, aided by two pairs of ***maxillae*** (mak-*sil*-ee), or little jaws. The jaws work from side to side and not up and down — they are merely leg-like appendages adapted for chewing and therefore continue to have a horizontal motion as do the legs.

The first appendages of the thorax are three pairs of ***maxillipeds***, or jaw feet. They hold food during chewing. The next and most obvious structures


Compound eye
Antennule
Cheliped
Antenna
Rostrum
Head
Thorax
Cephalothorax
Walking legs
1st Segment
2nd Segment
3rd Segment
4th Segment
5th Segment
6th Segment
7th Segment (Telson)
Abdomen
Uropod
DORSAL VIEW
Base of antennule
Base of antenna
Compound eye
Mouth
Mandible
Maxilla
Maxilliped
Gills
VENTRAL VIEW OF HEAD
Swimmerets
Anus
VENTRAL VIEW OF TAIL

30-1 The crayfish (dorsal view on the left, ventral view on the right) is a common crustacean.

are the ***chelipeds,*** or claw feet, which function in food-getting and protection. The next four pairs of legs are called ***walking legs.*** Feathery ***gills,*** the respiratory organs, extend under the carapace and are attached to all the thoracic appendages.

The abdominal appendages of the crayfish are called ***swimmerets.*** These appendages are used in swimming and in the female serve as a place of attachment for eggs. The sixth pair of appendages is much larger than the first five pairs. It is developed into a flipper, or ***uropod*** (*yur*-o-pahd). There is no appendage on the seventh segment, which is reduced to a flat, triangular structure — the ***telson.*** Strong abdominal muscles can whip the sixth and seventh segment forward, causing the animal to shoot backward at a rapid pace.

Structures that are believed to have developed from the same origin are said to be ***homologous,*** regardless of use. The appendages of the crayfish are considered to be homologous organs. Each segment except the telson bears a pair of appendages. The antennae and chelipeds of crayfish are homologous to the swimmerets. Homology can also be applied to different kinds of animals. The foreleg of the horse and the arm of the man, for example, are considered to be homologous because they are developed in a similar manner and from embryological counterparts.

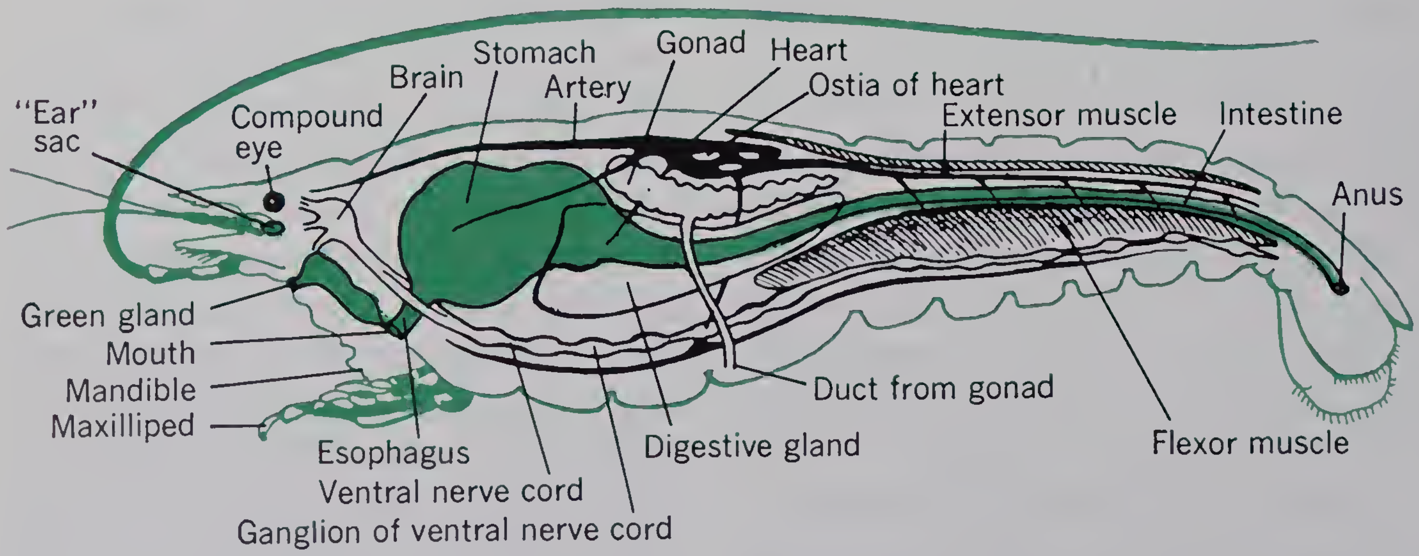
Analogous is another term frequently used in comparative anatomy and indicates a similarity in function. The wing of the bird and insect are analogous because they both function in flying. They are not homologous, however, because each develops in a different way and from different structures. The gills of the crayfish and the lungs of man are analogous because they both perform the function of respiration. They are not homologous since the gills are developed from the legs. The lungs are outgrowths of the throat.

Digestion in the crayfish. After food has been chewed by the mandibles and maxillae, it passes through the mouth and short esophagus to the stomach, which is lined with hard, chitinous teeth. These grind the food into smaller particles. When the particles of food are finely ground, they pass through folds of tissue, which act as a strainer, into another portion of the stomach where the ground food is mixed with digestive juices. From here the digested food passes into the digestive glands, where absorption takes place. Undigested particles pass on through the intestine, instead of entering the digestive glands, and are eliminated through the anus (Fig. 30–2). There are also excretory organs in the crayfish called ***green glands***, which lie anterior to the stomach and open close to the base of the antennae.

Circulatory and nervous systems. The colorless blood of the crayfish is pumped by the heart into seven large arteries which pour the blood over the major organs of the body. Blood is collected in a number of spaces, or sinuses. One large sinus surrounds the heart. From here blood enters the heart through three pairs of openings. This method of circulation of blood is called an ***open system.***

The nervous system, though similar to that in annelids, is more specialized. Receptors sensitive to odors and flavors are located in the antennae. The compound eyes each consist of numerous lenses, but sight is probably not keen. The hearing apparatus is located in a sac in the basal segment of each antennule. Hearing is poorly developed. Numerous sensory bristles distributed all over the body, especially on the surface of the antennae and other appendages, are sensitive to touch.

The sac at the base of each antennule is also concerned with balance. The lining of this sac is called a ***statocyst.*** At the time of molting the crayfish normally places a grain of sand in the statocyst, which is lined with short hairs. Figure 30–2 shows the nerve endings at these hairs. When the animal is right side up, pressure on the hairs by the grain of sand at the bottom of the statocyst stimulates the nerves and the crayfish senses its position in the water. Similarly, if it is upside down, the stimulation of the hairs in



30-2 In this longitudinal section of the crayfish, the term *gonad* refers to the ovary in the female and the testis in the male.

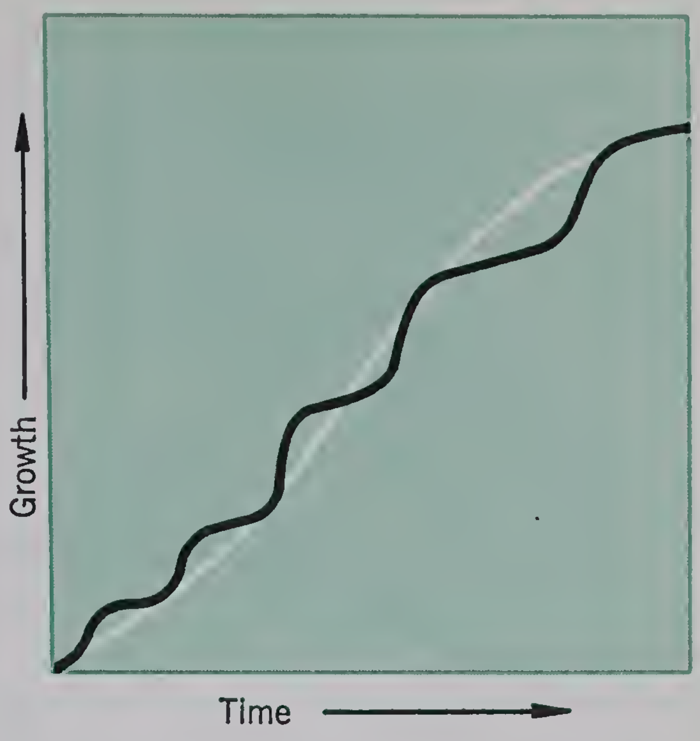
the statocyst informs the animal to right itself.

An interesting result occurs if a crayfish molts in an aquarium in which the sand has been replaced by iron filings. After the shell hardens, the animal is put in another aquarium. A magnet will cause the iron filing to stimulate the hairs in the top of the statocyst. The crayfish will turn on its back and stay upside down as long as the magnet is present.

How the crayfish respires. Gas exchange in protists is accomplished by diffusion through the plasma membrane; in worms, through the body wall. Crayfish have gills, which are organs especially adapted for the exchange of oxygen and carbon dioxide between the animal and its environment. These thin-walled gills are richly supplied with blood vessels to receive oxygen and carry it to all the cells, and also to liberate carbon dioxide.

The gills are arranged to insure a constant flow of fresh water over them. They move in the water with every motion of the legs or maxillipeds. The gills are protected by the carapace, which extends over them and forms a chamber. This chamber can hold moisture for some time, thus keeping the animal alive when it is removed from the water.

Reproduction and growth in the crayfish. Crayfish usually mate in the fall, at which time the sperm are stored in small receptacles on the lower side of the female's body. As the eggs, which number about one hundred, are laid in the spring, they are fertilized by the stored sperm and then attached to the swimmerets. Here these berrylike structures are carried and protected for about six to eight weeks until they hatch. As in the development of many invertebrates, the speed of development may depend on external factors of the environment, such as temperature and water conditions. The larvae are quite different from the parent, but during a series of molts they reach the adult form.



30-3 The pattern of growth in the arthropods is drawn in black; that of the vertebrates appears in white. Why can we compare arthropod growth, or molting, to a flight of steps?

From the time of hatching until the adult size, molting occurs at increasingly long intervals. Most crayfish molt seven times the first year and about twice a year thereafter. The average life span of the crayfish is three or four years.

During the process of molting, the cuticle secretes an enzyme which actually digests the inside of the shell, thus loosening it from the body. The carapace splits along the back, and water is withdrawn from the tissues, causing them to shrink. Next the animal literally humps itself out of its former skeleton. It also sheds the lining of its stomach and its teeth. Immediately following this process, water is absorbed and the animal swells up. When the lime is replaced, the exoskeleton hardens and the animal has grown. Since the crayfish is helpless at the time of molting, the process usually takes place quickly and in hidden locations.

During molting or in battle with enemies, appendages are often lost or injured. An injured limb is voluntarily shed. A double membrane prevents much loss of blood, and a whole new appendage is gradually developed to replace the injured member. This process is another example of regeneration of lost parts.

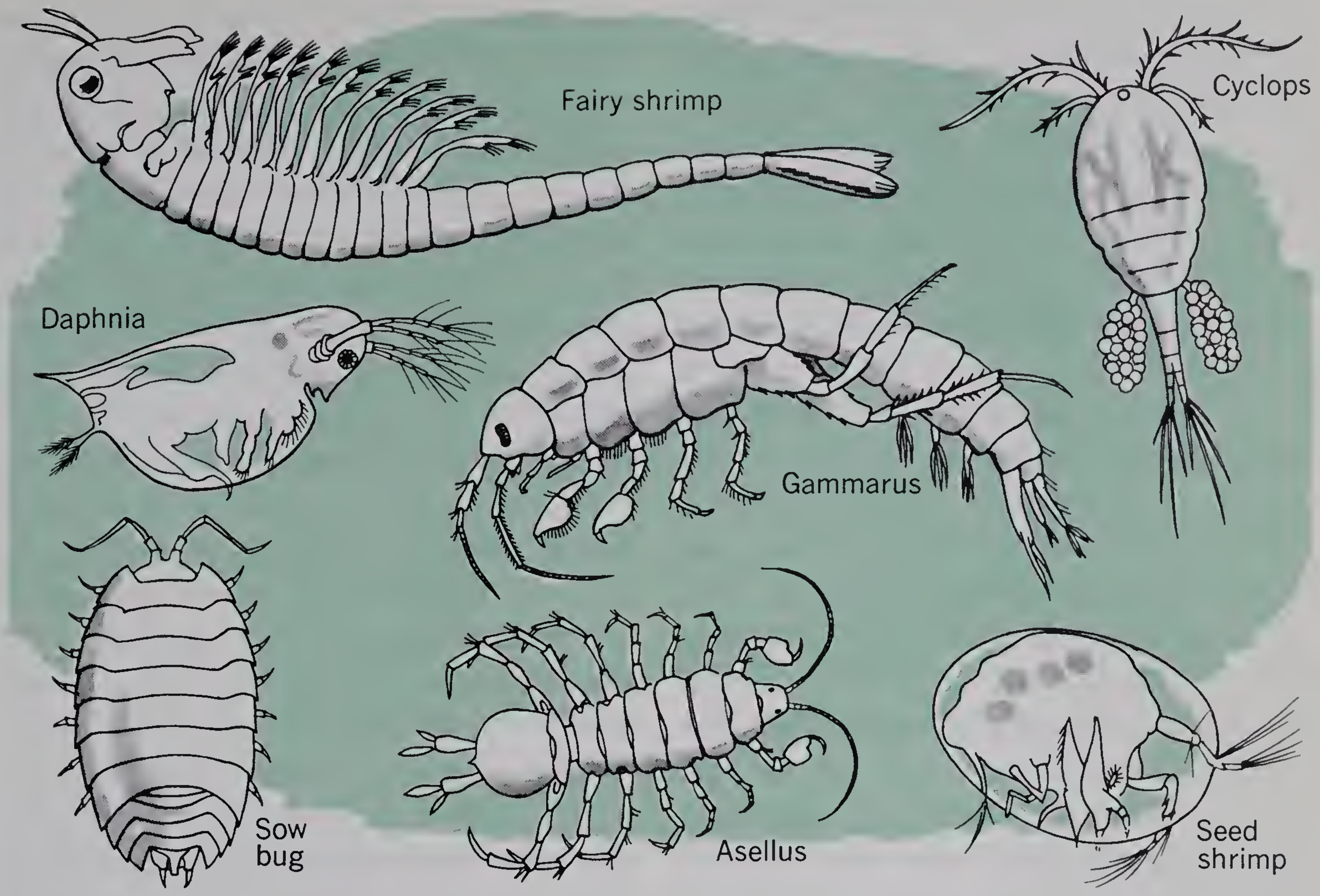
Economic importance of various crustaceans. Since the crayfish readily consumes dead organisms in any condition, it is considered of benefit as a scavenger. In certain parts of the country, especially in the Mississippi River basin, crayfish cause extensive damage by making holes in earthen dams and levees and by burrowing in fields, thus destroying cotton and corn crops.

The *spiny lobster* is an edible crustacean which lives in warmer regions of the oceans along the coasts of Florida, California, and the West Indies. This species lacks the large chelipeds possessed by the cold-water, northern form. The extremely long antennae and the spines covering the anterior region of the body are other characteristics of the spiny lobster.

The *blue crab*, which inhabits shallow, grassy ocean bays, is another highly prized crustacean. If these are caught immediately after molting, their cuticles have not hardened into shells. In this form they are called "soft-shelled crabs" and considered a delicacy, as the animal may be cleaned, fried, and eaten without being shelled. The body of the crab is shorter and broader than that of the lobster. The abdomen is reduced in size and folded under the cephalothorax. The cavity thus formed protects the gills and also serves as a brood pouch in which eggs are carried by the female.

Another edible crustacean is the *shrimp*. Shrimps have a highly muscular abdomen and are stronger swimmers

30-4 A spiny lobster. (Kinne — Photo Researchers, Inc.)



30-5 These forms of small crustaceans are usually found in ponds, streams, or moist places on land. What characteristics do they have in common?

than the bottom-dwelling crabs and lobsters. They swim backward in true crustacean fashion. If alarmed, many shrimps bury themselves in the sand and thrust out their eyes and antennae to maintain contact with their environment. In the Gulf Coast states and in California, the shrimp industry is very important. Louisiana, Texas, and California supply much of the shrimp for inland markets.

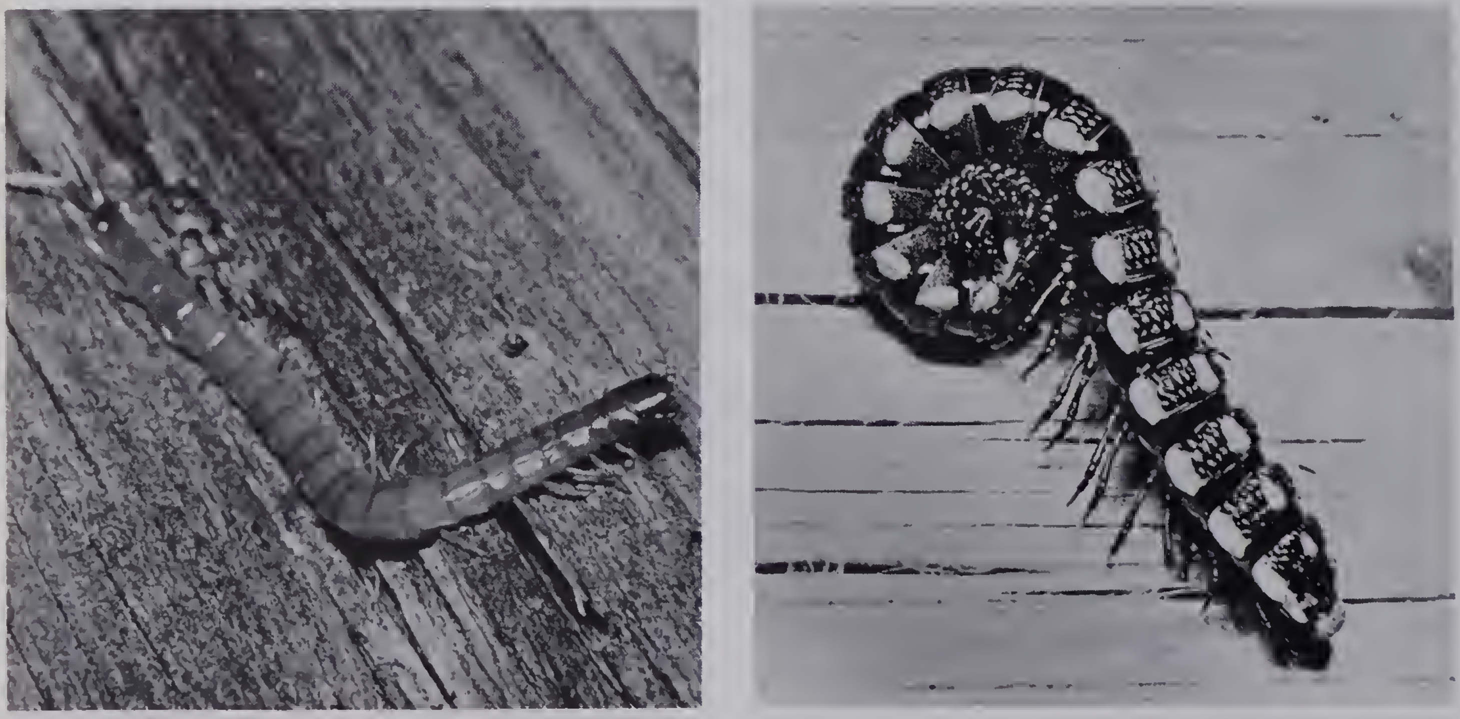
Crustacea are adapted for a variety of environments. The edible marine crustaceans are relatively insignificant in terms of numbers of individuals. The vast majority of crustaceans consist of minute and even microscopic forms. The major diet of the large whale is tiny shrimps under an inch in length. Small crustaceans may occur in such tremendous numbers that the sonar apparatus of ships will give false readings of the bottom depth.

Artemia, the brine shrimp, inhabits tide pools and may withstand a highly concentrated salt-water environment. Many tropical fish enthusiasts buy the eggs and raise the shrimp for fish food. *Barnacles* are sessile crustaceans which, in larval form, settle down on a solid object, produce a shell, and use their feet to kick food into their mouths. Barnacles may accumulate on the hulls of ships in numbers large enough to reduce the speed as much as 20 percent. They also clog sea-water intake pipes and grow on piers. Here the accumulation of sand and decaying organic matter between the barnacles provides a good medium where bacteria live and grow. In turn annelids and other smaller animals feed on the bacteria. The barnacles, usually associated with mussels, actually change the environment of wharf pilings by providing protection against wave action, extreme temperature changes, and drying at low tides. These environmental changes, however, do not make man happy, as they increase the speed of deterioration of the wharves.

The crustaceans are by no means limited to a marine environment. In nearly every sample of fresh water, many tiny brownish specks will zig-zag before your eyes. These organisms may be *Daphnia* (water fleas) or *ostracods*. The ostracods are tiny crustaceans which, in addition to the chitinous exoskeleton, secrete two shells resembling those of clams. Other common minute Crustacea are the *copepods* (*koh*-pe-pahdz), which serve as an important part of the diet of many fish.

Another interesting adaptation of the crustaceans may be observed in the terrestrial isopods. These animals are the *sowbugs* and *pillbugs*. Since they have seven pairs of identical legs, they are called *isopods*, which means "same feet." If you do not live near a stream where crayfish can be found or near the ocean where other Crustacea can be studied, these terrestrial crustaceans are usually available. The gills of their aquatic cousins are missing in these terrestrial forms; but a series of plates along the ventral surface of the abdomen has tiny tubes in which air may pass and through which respiration occurs. Since these plates must be kept moist, sowbugs and pillbugs are usually found under damp stones and logs. Terrestrial isopods may be kept for weeks by keeping them in jars with potato or carrot slices.

"Hundred-leggers" and "thousand-leggers." The Chilopoda and the Diplopoda are often grouped together as one class, the *Myriapoda*, which means "many feet." Perhaps you have wondered how a centipede or millepede can operate so many legs and not get them tangled in one another. Their movement is certainly an excellent example of coordination. These curious worm-



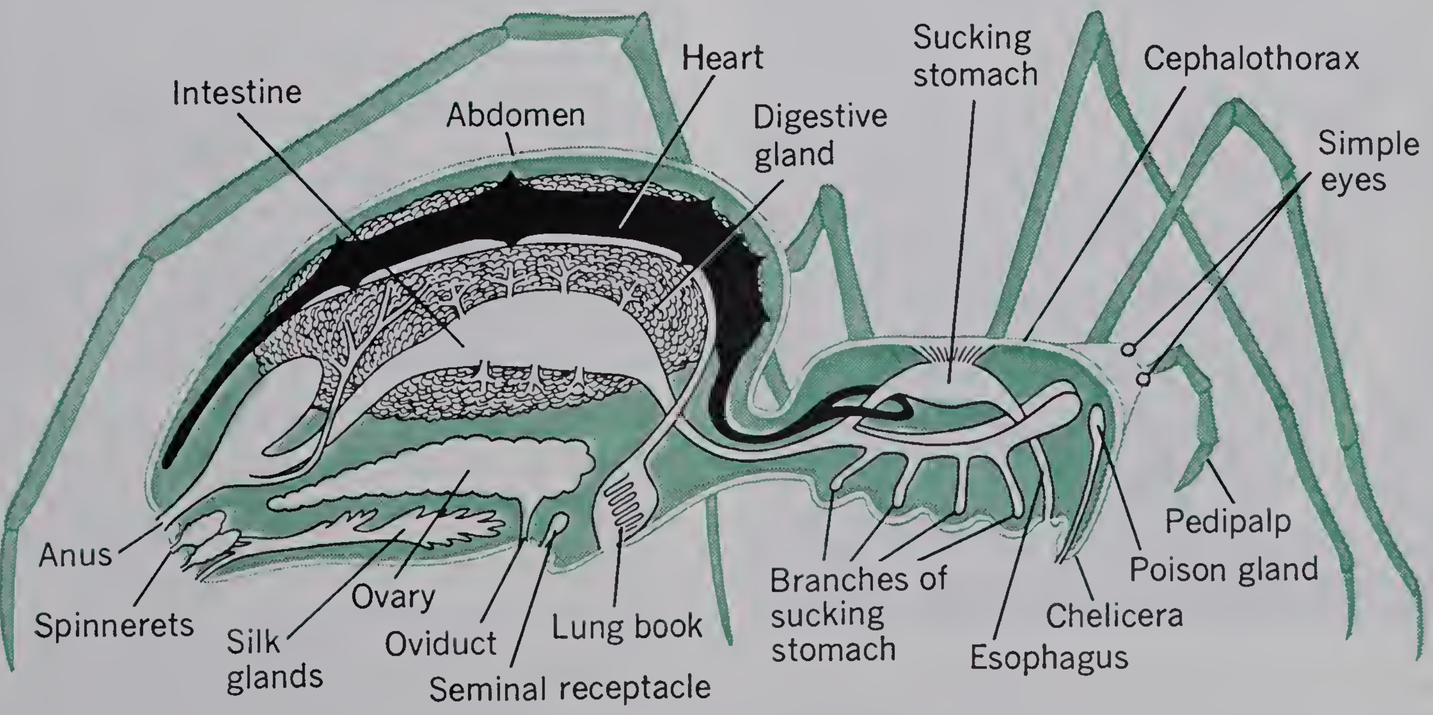
30-6 Centipede (left); millepede (right). How do they differ? (Walter Dawn) like arthropods are often seen racing away with a rippling motion when their hiding place under a log, stone, or piece of rubbish has suddenly been disturbed.

Centipedes belong to the class ***Chilopoda*** and have bodies composed of many segments. The head bears the antennae and mouthparts; the first body segment bears a pair of poison claws; each succeeding segment, except the last two, bears one pair of walking legs (Fig. 30–6).

Millepedes, or "thousand-leggers," belong to the class ***Diplopoda*** and also have bodies composed of many segments. As in the centipede, the head bears antennae and mouthparts; all the body segments except the last two bear two pairs of legs each. Hence the name *Diplopoda,* which means "double feet." Millepedes are frequently slow moving and are likely to roll into a spiral when disturbed. Centipedes, on the other hand, are fast moving and difficult to capture. In tropical countries centipedes may measure 12 inches in length, and their bites may be quite poisonous. Some have as many as 173 pairs of legs, but 35 is average.

Spiders – familiar arachnids. Unfortunately spiders are one of several groups of valuable animals whose reputations have been spoiled by a few undesirable members. With a few exceptions spiders are extremely valuable because they destroy harmful insects. They belong to the class ***Arachnida*** (a-*rak*-nid-a). Some kinds of spiders, called *orb weavers,* spin elaborate webs of tiny silken threads which are remarkable engineering feats. The web serves as a trap for capturing flying insects. When a victim becomes entangled in the sticky threads of the web, the spider races from its hiding place along the margin. Its bite poisons the prey. When the insect has become partially paralyzed, the spider binds it securely in a case of threads spun around the victim as the spider turns it over and over. Other spiders do not spin webs, but live as solitary individuals stalking their prey as they roam about.

The spider resembles an insect but differs in several respects (Fig. 30–7). It has eight legs instead of six, and the head and thorax are joined to form a cephalothorax as in the Crustacea. The



30-7 Longitudinal section of a female spider.

first pair of appendages, the *chelicera*, serves as poison fangs, and for sucking the juices from the victim's body. The second pair of head appendages in the spider is called *pedipalps*. These appendages are sensory and are used especially in reproduction by the male spider. On the tip of the abdomen of many spiders are three pairs of *spinnerets*. Each spinneret consists of hundreds of microscopic tubes through which the fluid silk flows from the silk glands. When the silk passes into the air it hardens into a thread. This silk is used in making the spider's web, to build cocoons for eggs, to build nests, and as a guide so the spider can find its way back home. Young spiders of many species spin long silken threads which catch in the wind and carry them to distant places. This procedure is known as *ballooning*.

30-8 The orange garden spider spins a beautiful orb web to trap insects. (Hugh Spencer)

30-9 The black widow spider is recognized by its round, black abdomen and the vivid red spot on its ventral surface. (Gerard from Monkmeyer)

Most spiders have two types of respiratory organs. A pair of air-filled sacs called *lung books*, situated on the lower side of the abdomen, receive air through slit-like openings. Numerous leaves, or plates, of the lung books provide a large surface for exposure to air. In addition to lung books, many spiders have air tubes resembling tracheae of insects with openings situated on the abdomen.

The mature male spider can be distinguished from the female usually by size alone — the male is usually the smaller. In species where there is no size difference, the pedipalps of the male are much larger near the tips. At maturity the male transfers sperm to special sacs at the tips of the pedipalps. These sperm are then placed in the *seminal receptacle* of the female, who sometimes devours the unfortunate smaller male afterward. At the time of egg-laying, the eggs are fertilized as they pass out the genital pore and into a nest or cocoon the female has prepared.

Among the most famous spiders are the *tarantula* (ta-*ranch*-uh-la), or banana spider, the *black widow*, famous for its very poisonous bite, and the *trapdoor spider* of the western desert regions.

Other arachnids. Spiders are related to many other forms of animal life. *Scorpions*, found in southern and southwestern United States and in all tropical countries, are provided with a long segmented abdomen terminating in a venomous stinger. The sting of a scorpion, while painful, is seldom fatal to man. Campers find scorpions annoying in that they like to crawl in empty shoes during the day to escape bright light. Scorpions live solitary lives except when mating, after which the female often turns on her mate and devours him. The young are brought forth alive and spend the early part of their existence riding on the mother's back.

The *harvestman*, or *daddy longlegs*, is one of the most useful of the arachnids since it feeds almost entirely on plant lice. It leads a strictly solitary life, traveling through the fields in search of its prey.

30-10 The sting of a scorpion, which is inflicted from the end of the tail, is intended for small prey but can be very painful to man. (Albert Towle)

30-11 This photograph shows a chigger magnified over 50 times. The animal has eight legs as do all arachnids and its bite causes extreme discomfort in man. (American Museum of Natural History)

Mites and *ticks* are among the more notorious arachnids, causing considerable damage to man and other animals. They live mostly as parasites on the surface of the bodies of chickens, dogs, cattle, man, and other animals. Some forms, like the Rocky Mountain tick, carry disease organisms.

Harvest mites, or *chiggers*, are immature stages of mites which attach themselves to the surface of the skin and insert beaks through which they withdraw blood (Fig. 30–11). They are almost microscopic in size and give no warning of their presence until a swollen area causes great itching and discomfort. After a few days the sore becomes covered with a scab and disappears.

IN CONCLUSION

The arthropods are the largest single group of animals, with more different forms than all other animal groups combined. They can swim, crawl, hop, run, burrow, and fly. Their diversity has allowed them to utilize all environments — fresh water, marine, and terrestrial — and to explore almost every environment available to animals.

In the next chapters we shall consider representatives of the insects, the most abundant class of arthropods.

BIOLOGICALLY SPEAKING

abdomen
analogous
antennae
antennules
appendage
Arachnida
Arthropoda
carapace
cephalothorax
chelicera
chelipeds
Chilopoda
chitin
compound eyes
Crustacea
Diplopoda
exoskeleton
gills
green glands
homologous
Insecta
mandibles
maxillae
maxillipeds
molting
open circulatory system
rostrum
statocyst
swimmerets
telson
uropod
walking legs

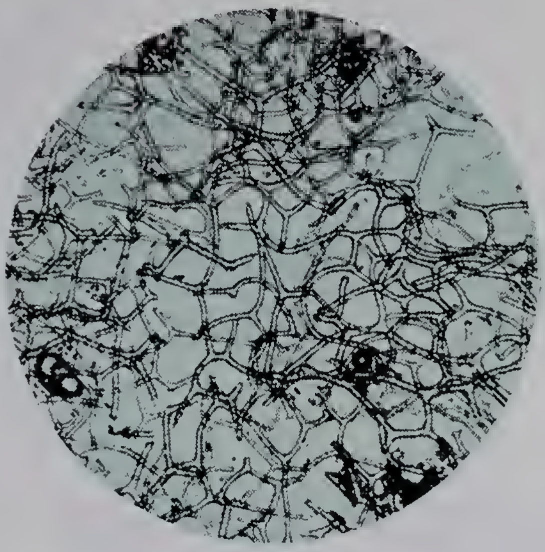
QUESTIONS FOR REVIEW

1. What are three external characteristics of an arthropod that distinguish it from other animals?
2. Name the five principal classes of arthropods, and give examples of each.
3. In what ways are the arthropods similar to the earthworm?
4. What are some advantages and disadvantages of an exoskeleton?
5. How do the gills in the crayfish carry on the process of respiration?
6. To what stimuli is the crayfish sensitive, and what structures assist in the sensitivity?
7. How does a centipede differ from a millepede?
8. Why are most spiders extremely beneficial animals? What reasons can you give for the fact that many people are genuinely afraid of arachnids?
9. Of what value is ballooning to the spider?
10. What other animals besides the spiders are classified as arachnids?

APPLYING PRINCIPLES AND CONCEPTS

1. Why is it especially important for an armored animal like the crayfish to have long antennae?
2. In which of the following localities do you think the crayfish would be likely to produce weaker exoskeletons — in waters flowing through limestone rock or in waters flowing through granite? Explain.
3. Of what advantage to the young crayfish is its clinging to the adult's swimmerets until after the second molting?
4. How do barnacles do damage in other ways than reducing a ship's speed?

CHAPTER 31



INSECTS–A REPRESENTATIVE STUDY

Vast numbers of species. The study of insects is called ***entomology,*** and the scientists specializing in this field are *entomologists.* Entomologists have already recorded more than 675,000 species of insects, and they regard this as not more than half of all insects in existence! Three quarters of all classified animals are arthropods, and of these, the class Insecta is by far the most numerous. Not only are there many kinds of insects, but each kind produces thousands of offspring. Consider, for example, the locusts and mayflies, whose swarms can darken the skies. Thomas Huxley, the famous English biologist, made the following calculation:

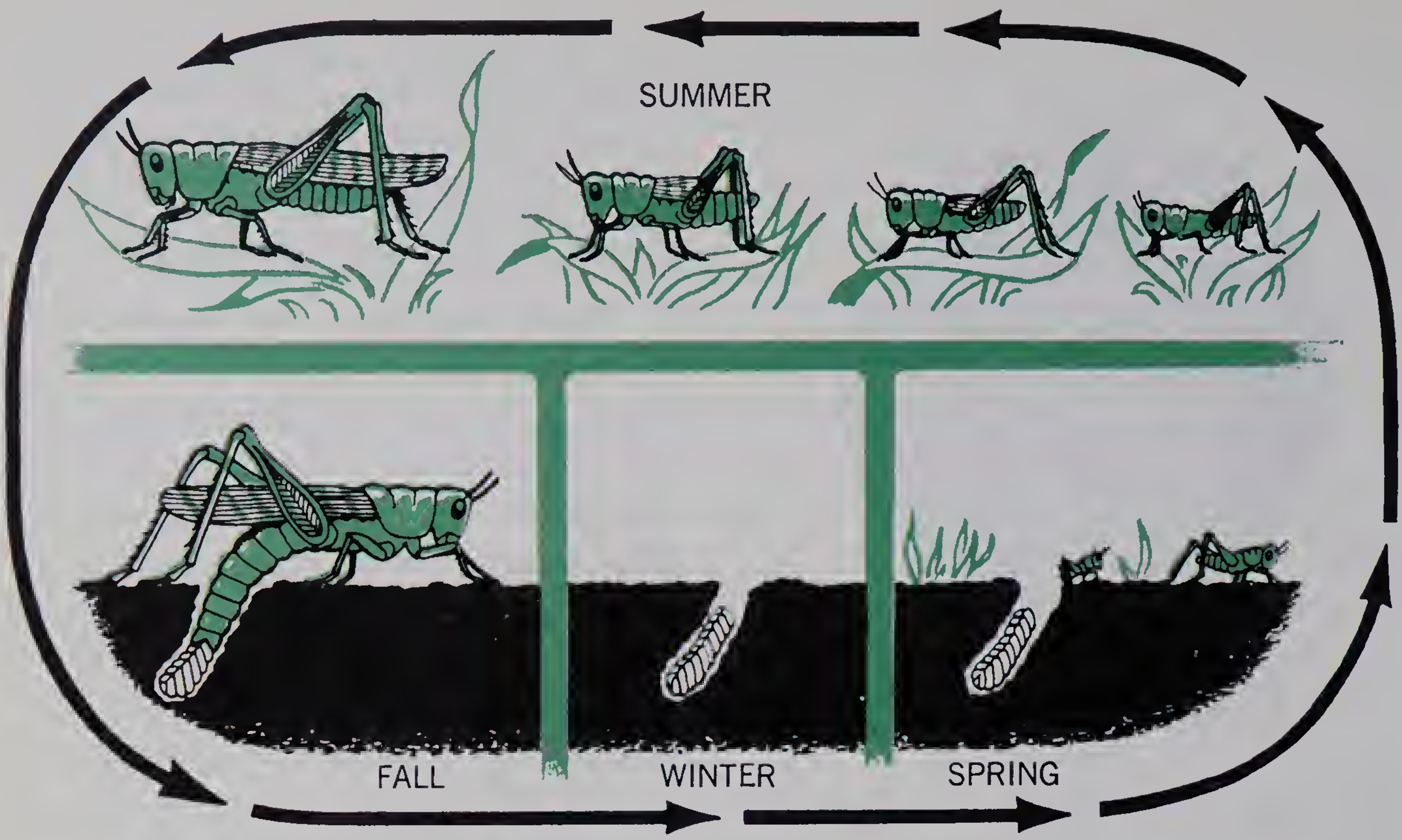
> I will assume that an *Aphis* weighs one-thousandth of a grain, which is certainly vastly under the mark. A quintillion of Aphides will, on this estimate, weigh a quatrillion of grains; consequently, the tenth brood alone, if all its members survive the perils to which they are exposed, contains more substance than 500,000,000 stout men — to say the least, more than the whole population of China!

So varied are the food requirements of insects that they can maintain tremendous numbers without interfering with each other. There are leaf feeders, plant sap feeders, blood suckers, flesh eaters, wood eaters, nectar and pollen gatherers, and even cannibalistic insects. Their small size, exoskeleton, flight, and various colorings are but a few of the protective mechanisms of insects. Fortunately, as we shall see in the final unit of this book, other factors control this reproductive potential.

How to recognize an insect. Many people speak of any small flying or crawling animal as a "bug." They are wrong on two counts! First, a true bug is a member of only one order of insects. Second, what some people call a bug may be a spider or a centipede. These, of course, are not insects at all.

Insects include that division of the arthropods which has three separate body regions: 1. *head;* 2. *thorax;* and 3. *abdomen.* The head bears one pair of antennae and three pairs of mouthparts. The thorax of an insect bears three pairs of legs and in many the wings. The abdomen has as many as 11 segments and never bears legs. The reproductive structures are usually found on the eighth, ninth, and tenth segments. Insects breathe by many branched tubes called ***tracheae*** (*tray-kee-ee*).

A high degree of specialization. The mouthparts of insects are adapted for different kinds of food. Some insects have chewing mouthparts with strong jaws to grind up leaves. Some have



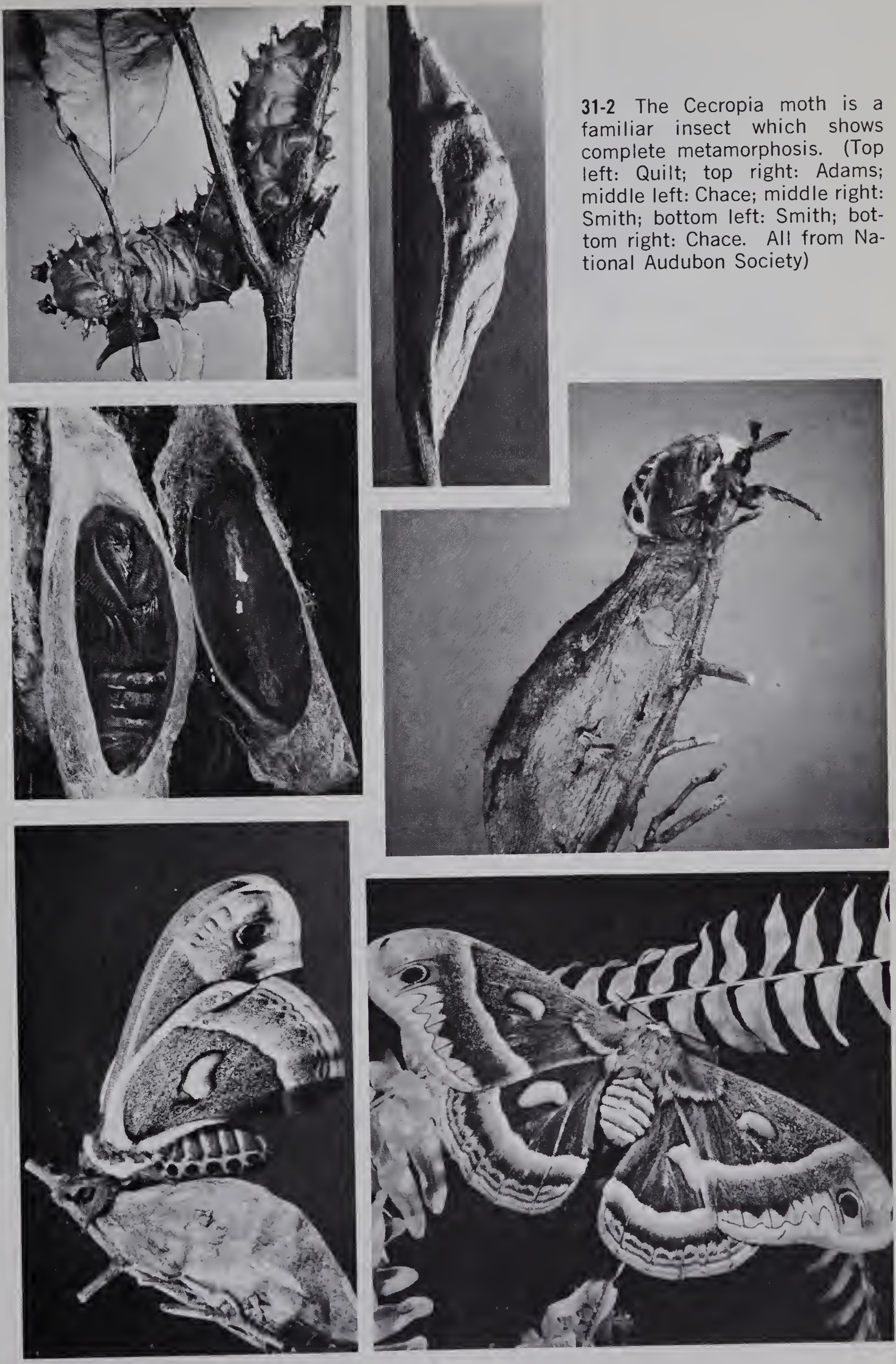
31-1 The life history of the grasshopper shows incomplete metamorphosis.

piercing and sucking mouthparts with which they are able to suck plant juices or blood from animals, as do the mosquitoes. Some have a siphoning tube for probing flowers to obtain the nectar. You have all seen butterflies gathering the nectar from flowers on warm days.

The wings and legs of many insects are developed for swift locomotion. Some insects are adapted for aquatic life and some for burrowing in the ground. Some insects live in colonies; others fight their battles alone. Some, such as the scale insects, have in the process of evolution lost their legs entirely.

Insect metamorphosis. Most insects undergo several distinct stages during development from egg to adult. Such a series of stages in a life history is called *metamorphosis*. Grasshoppers and their relatives, true bugs, aphids, termites, and many other insects have ***incomplete metamorphosis.*** This is a three-stage life history consisting of: 1. the *egg*; 2. the *nymph*; and 3. the ***adult.*** A nymph hatches from an egg in a form resembling the adult except for size, absence of wings, and lack of development of the reproductive organs. In most species nymphs molt five times, each time becoming more like the adult.

Butterflies, moths, flies, and beetles are among the insects with ***complete metamorphosis.*** They pass through four stages in their development: 1. ***egg***; 2. ***larva***; 3. ***pupa***; and 4. ***adult.*** The larvae that hatch from eggs are segmented and wormlike. They are called by such names as caterpillar, grub, or maggot, depending on the kind of insect (see table, page 426). After a period of feeding and rapid growth, the larva enters the pupa stage. This is often thought of as a resting stage because changes occur within a shell or case and cannot be seen externally. It is anything but a resting period, however, because in this stage all the tissues of the larva are transformed into those of the adult. The



31-2 The Cecropia moth is a familiar insect which shows complete metamorphosis. (Top left: Quilt; top right: Adams; middle left: Chace; middle right: Smith; bottom left: Smith; bottom right: Chace. All from National Audubon Society)

THE LARVA OF THE	IS CALLED
beetle	grub
fly	maggot
mosquito	wiggler
butterfly	caterpillar or "worm"
moth	caterpillar or "worm"

change from caterpillar to butterfly or grub to beetle is truly a marvelous event in nature.

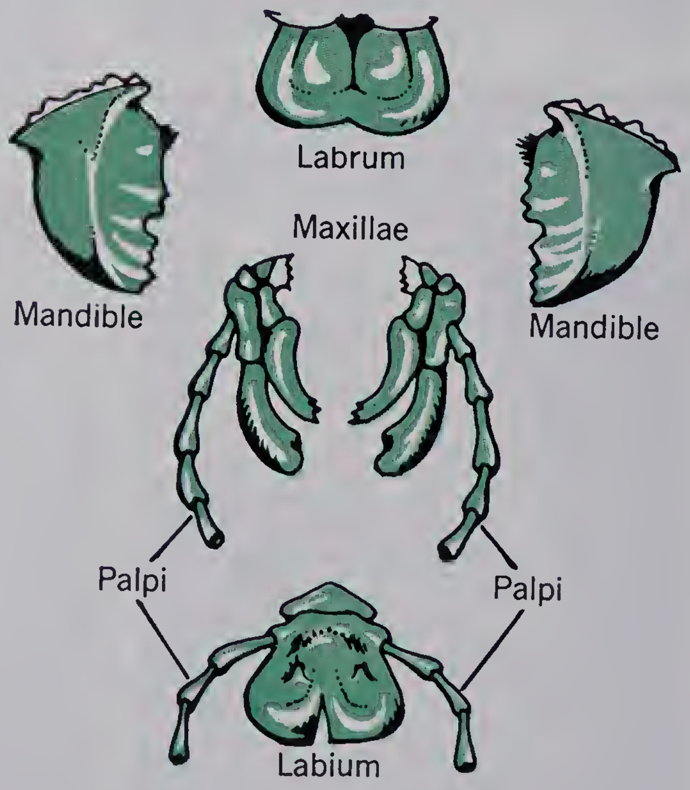
In recent years, biologists have been investigating the role of hormones in insect metamorphosis. They have found that two hormones, a *juvenile hormone* and a *growth hormone*, are involved in the transformation of a nymph of the bug, *Rhodnius*, into an adult. These hormones were found in a gland near the brain and in a mass of tissue within the brain.

In studies of the metamorphosis of the Cecropia moth, it was found that a juvenile hormone stimulates growth of the larva but ceases to function when the moth enters the pupa stage. Two additional hormones, one secreted in the brain and one in a gland of the thorax, are necessary for development of the insect in the pupa stage.

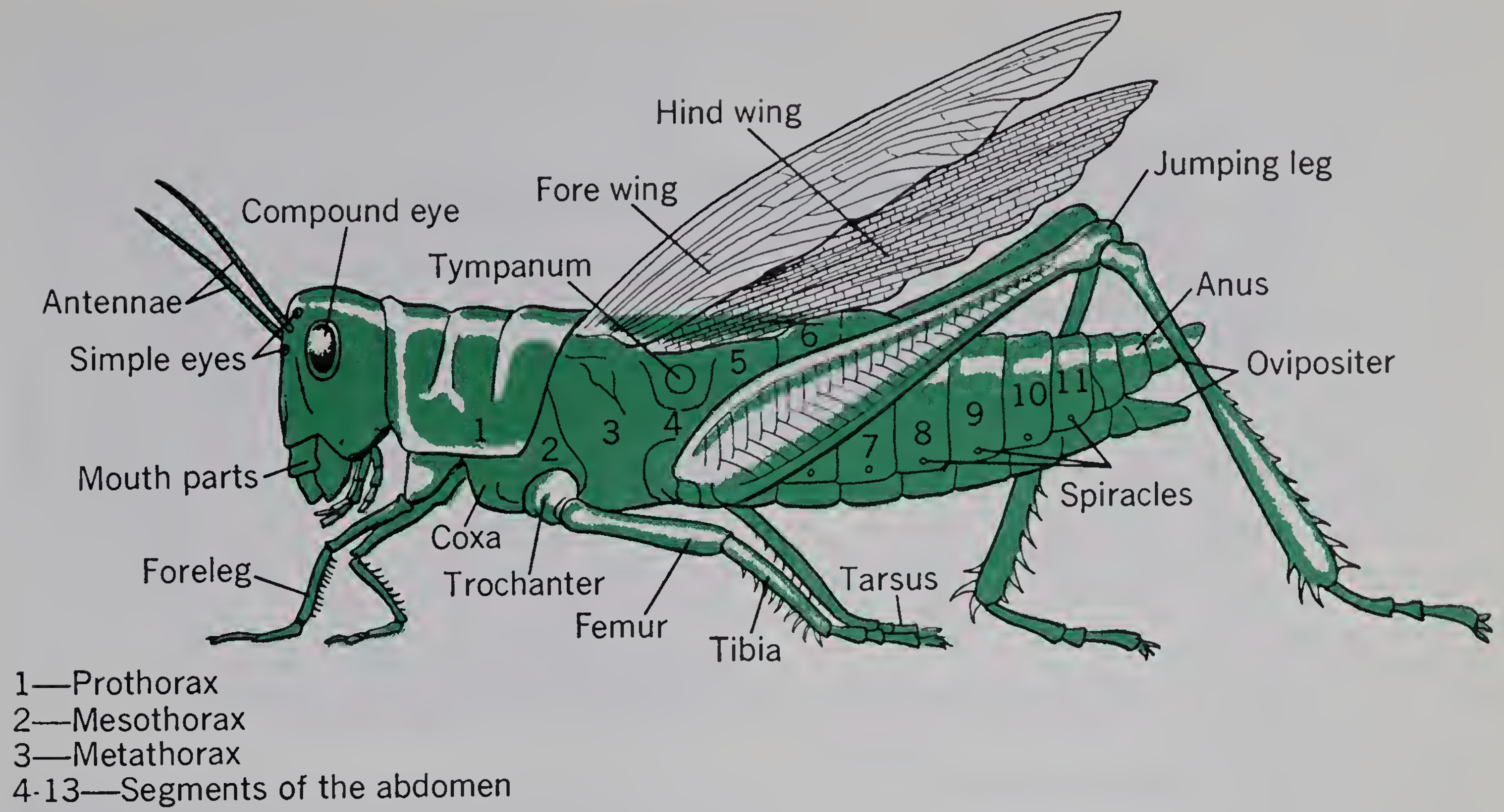
A closer look at a representative insect. By this time you are aware that a high school course in biology cannot possibly cover the entire subject. When a large group of organisms is studied, we often choose one that shows the characteristics of the group. We cannot say that a grasshopper, for example, is a typical insect because the diversity of this class is unequaled in the animal kingdom. The grasshopper, however, is large enough to examine without high magnification and is common enough to be available in large numbers.

As a member of the order ***Orthoptera***, which means "straight-winged," the grasshopper's narrowly folded wings are held straight along the body when not actually used in flight. As in all arthropods the skeleton is external, but it differs from the crayfish in that it contains no lime. It consists entirely of the light, tough substance called chitin.

Since the herbivorous grasshopper feeds on blades of grass, let us examine the mouthparts to see how they are adapted for this food. The ***labrum*** is a two-lobed upper lip used in keeping a blade of grass at right angles to the ***mandibles***, which are toothed, horizontal jaws (Fig. 31–3). Lying posterior to the mandibles are paired ***maxillae***. These are accessory jaws which aid in holding and cutting food. The ***palpus***



31-3 The mouthparts of the grasshopper are especially adapted for chewing plant materials. The mandibles are notched and they move sideways.


Hind wing
Fore wing
Compound eye
Tympanum
Antennae
Simple eyes
Mouth parts
Foreleg
Coxa
Trochanter
Femur
Tibia
Tarsus
Jumping leg
Anus
Ovipositer
Spiracles
1
2
3
4
5
6
7
8
9
10
11
1—Prothorax
2—Mesothorax
3—Metathorax
4-13—Segments of the abdomen

31-4 External structure of the grasshopper.

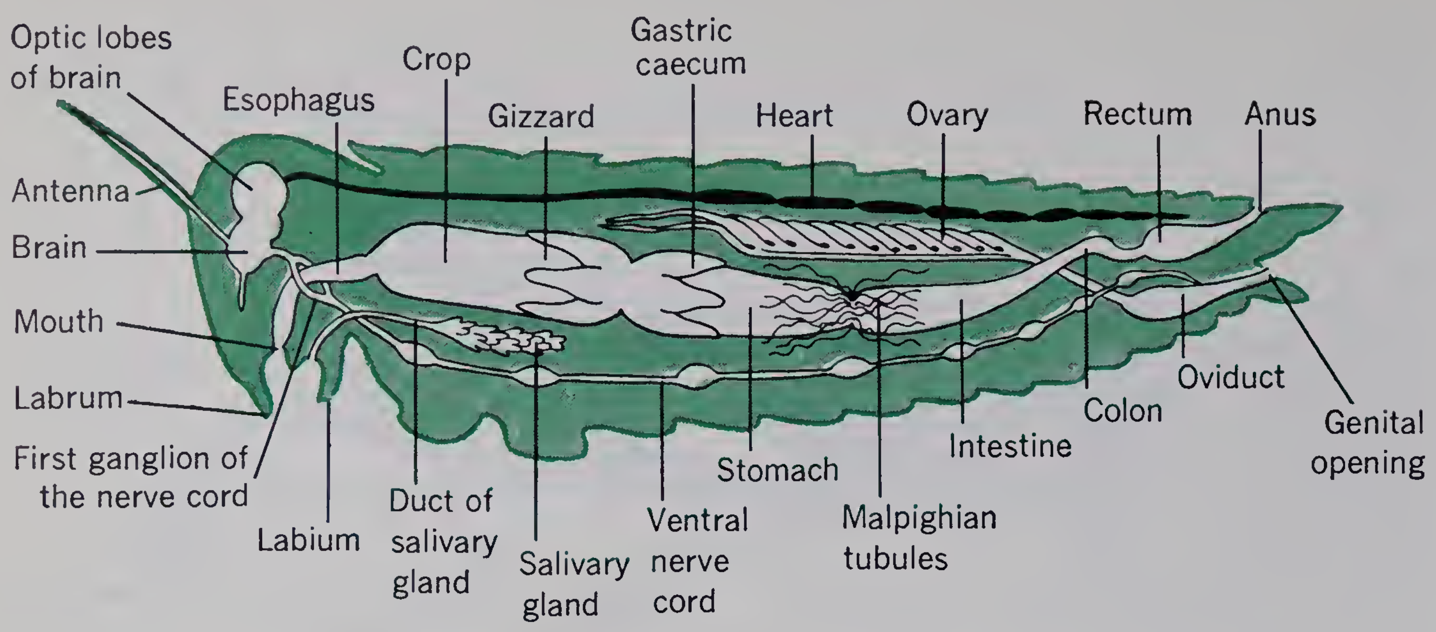
is an antennalike sense organ which is part of each maxilla. Posterior to the maxillae is the ***labium,*** or lower lip, also provided with palpi. This organ functions in holding food between the jaws. These mouthparts, like the legs of the crayfish, are believed to be homologous, as it is thought that each one developed as an appendage of an independent embryonic segment.

Locomotion may be accomplished in several ways. The grasshopper's locomotory appendages are located on the thorax, which is divided into three segments. The head and first pair of walking legs are attached to the ***prothorax*** (Fig. 31–4). The first pair of wings and the second pair of walking legs are attached to the ***mesothorax.*** The ***metathorax*** bears the second pair of wings and the jumping legs.

The grasshopper's wings may carry it over dry fields for a short distance or for many miles when they migrate in swarms. The long, narrow, and stiff *anterior* wings protect the delicate underwings when the grasshopper is at rest or walking, but during flight or leaping they act as planes. The *posterior* wings are thin and membranous and supported by many veins. These flying wings are folded like a fan when not in use.

For shorter distances the large jumping leg is used to escape enemies, to launch into flight, or to search for food. The jumping legs are also used with the walking legs to climb up plants in order to feed on the tender leaves. When the insect is jumping or walking, spines, hooks, and pads of the foot, or ***tarsus,*** aid in gripping. The long joint next to the tarsus is called the ***tibia.*** The large muscles for jumping are contained in the ***femur,*** the heaviest joint of the leg. The ***trochanter*** (troh-*kant*-er) joins the ***coxa*** near the body and together they act like a ball and socket joint in providing freedom of motion.

A remarkable respiratory apparatus. Each of the ten segments of the abdomen consists of two curved plates. The upper and lower plates are joined by a tough but flexible membrane that allows the segment to expand and con-


Optic lobes of brain
Esophagus
Crop
Gastric caecum
Gizzard
Heart
Ovary
Rectum
Anus
Antenna
Brain
Mouth
Labrum
First ganglion of the nerve cord
Labium
Duct of salivary gland
Salivary gland
Ventral nerve cord
Stomach
Malpighian tubules
Intestine
Colon
Oviduct
Genital opening

31-5 Internal structure of the grasshopper.

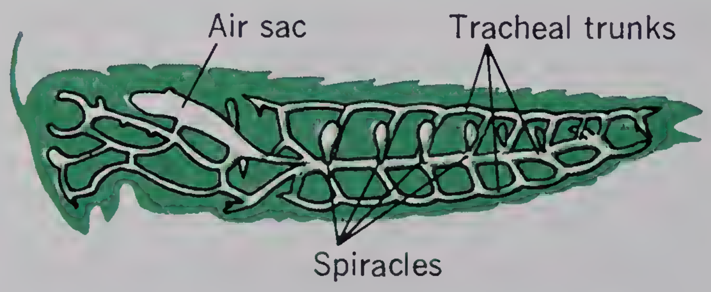
tract in the process of respiration. The flexible membrane also joins each segment with the anterior and posterior ones, allowing movement.

Eight of the abdominal segments have pairs of tiny openings, the ***spiracles.*** Spiracles are also found on the second and third thoracic segments. The openings lead to the tracheae, or air tubes, which form an amazingly complex network inside the animal. Air is pumped in and out of the tracheae by action of the wings and movement of the abdomen. Very rapid diffusion of oxygen into the tissues and carbon dioxide into the tracheae accomplishes respiration.

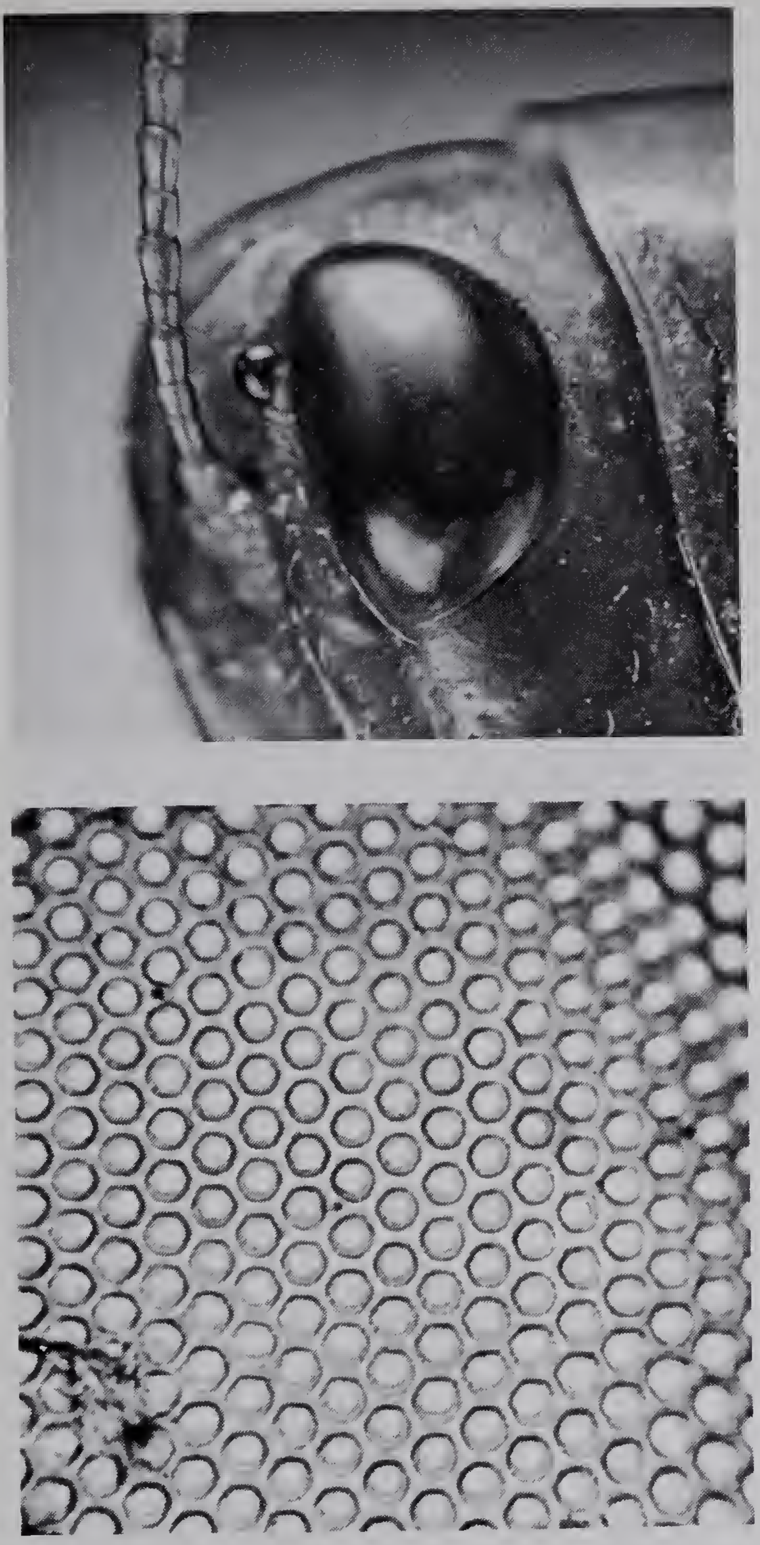
Digestion, excretion, and circulation. The horizontal action of the mandibles pinches off bits of grass, which are then sucked into the mouth. An ***esophagus*** carries the food to a ***crop,*** where it may be stored for a time. As in many animals ***salivary glands*** secrete juices which enter the mouth. These juices moisten the food to ease its passage to the crop. You may have seen regurgitated food from the crop when a grasshopper is injured or disturbed, but normally the food passes on to the ***gizzard.*** Here food is shredded by plates of chitin-bearing teeth.

Partially digested food is screened through thin plates and passes into the large ***stomach.*** Figure 31–5 shows three double pouches on the outside of the stomach. These are ***gastric caeca*** (*see*-ka), which produce and pour enzymes into the stomach, where digestion is completed. Digested food is absorbed into the blood stream through the wall of the stomach. The material remaining in the stomach passes into the ***intestine,*** which is composed of the ***colon*** and ***rectum*** and which terminates at the ***anus.***

Cellular wastes are picked up by the blood stream and collected by a series of tubes called the ***Malpighian*** (mal-*pee*-gee-an) ***tubules.*** The wastes are then passed into the last part of the intestine and out through the anus.


Air sac
Tracheal trunks
Spiracles

31-6 This diagram of the dissected abdomen of the grasshopper shows the arrangement of the tracheal system.



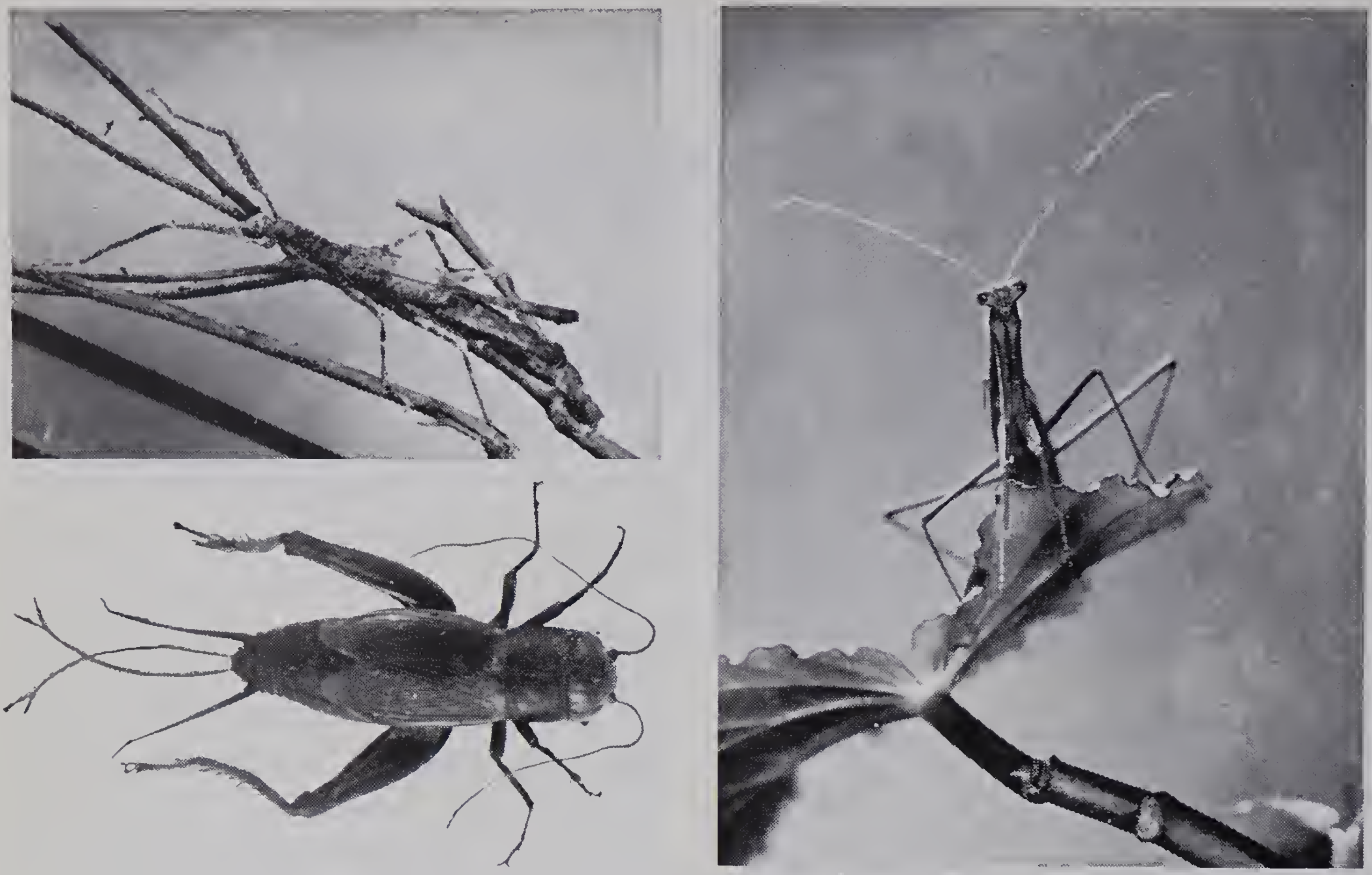
31-7 The upper photograph is of the simple and compound eyes of the grasshopper. The lower photo is a close-up of the compound eye. (Hugh Spencer)

The circulatory system of the grasshopper, like that of the crayfish, is an open system. Blood forced out the anterior end of the tubular, muscular ***heart*** passes through the ***aorta*** and into the body cavity near the head. As blood flows toward the posterior region, it bathes all the body organs and finally returns to the heart for recirculation.

What are the grasshopper's sensory responses? Each side of the first abdominal segment bears a membrane-covered cavity called the ***tympanum.*** These sensory organs function in hearing. Touch and smell are perceived by the many-jointed ***antennae.*** The grasshopper has two kinds of eyes. Figure 31–7 shows the ***simple eyes,*** located above the base of each antenna and in the groove between them. The large ***compound eyes*** project from a part of the front and sides of the head and are composed of hundreds of six-sided lenses. The shape, location, and number of lenses seem to adapt the insect for sight in several directions at one time, but the image formed is probably not very sharp. Most insects are considered to be nearsighted, yet they may be able to distinguish colors. We know that night-flying moths seek white flowers, while flies and some other insects are attracted by red and blue.

The stimuli received through the sense organs are then relayed by nerves to certain parts of the body, such as a muscle, which then contract. Nerve centers called ***ganglia*** act as switches in directing the message to the proper structures for coordinated action. The brain itself is an enlarged ganglion composed largely of ***optic lobes.*** The sight of your approaching hand is enough to cause the grasshopper to start moving away, and fast! This complicated activity is begun, controlled, and coordinated by the nervous system.

Reproductive organs of grasshoppers. In insects the sexes are separate. This means that sperm cells are produced in ***testes,*** found in the male. Egg cells are produced in ***ovaries,*** found in the female. The male deposits the sperm cells in a special storage pouch, the ***seminal receptacle,*** of the female. The sperm remain there until the eggs are ready for fertilization.



31-8 The cricket, the praying mantis, and the walking stick are relatives of the grasshopper. Identify each of these in the photographs. (Top left and right: American Museum of Natural History; bottom left: USDA)

The extreme posterior segments in the female grasshopper bear two pairs of hard, sharp-pointed organs called ***ovipositors*** (o-vi-*pahz*-i-tors). With these she digs a hole in the ground and deposits her fertilized eggs, which are protected by a gummy substance. About 100 or more eggs are laid in the fall and hatch in the next spring.

Relatives of the grasshopper. It is easy to see that the meadow grasshopper and the katydid are related. The wings of the katydid look much like leaves, even to the veining, so that these insects are well protected from their enemies. Other members of the Orthoptera are the cricket, roach, walking stick, and praying mantis. By destroying crops, the grasshopper and its relatives are harmful to man. Most of you have read stories or seen movies in which grasshoppers ("locusts") have plagued both the Old and New Worlds throughout history.

A useful relative of the grasshopper is the *praying mantis,* which eats other insects, many of which are harmful. Mantis egg cases are sold at many seed stores. When the eggs hatch in the spring, nymphs emerge and remain in the garden, where they mature and eat other insects.

IN CONCLUSION

As a member of the largest class of arthropods, the grasshopper has been used to illustrate the major characteristics of the insects. The grasshopper has the high degree of specialization typical of most insects.

The complex systems of the grasshopper allow it to respond to environmental stimuli in a coordinated manner. Its sense organs receive the stimuli, and the information is relayed to an enlarged ganglion, the brain. Nerves from the brain stimulate muscles to act. The action may be a slow and deliberate motion toward food; it may be a quick jumping to avoid being caught; or it may be a flight to carry it some distance.

To show what other variations this class of arthropods possesses, we shall continue with other orders of insects in the next chapter.

BIOLOGICALLY SPEAKING

adult
aorta
colon
complete metamorphosis
coxa
egg
entomology
femur
gastric caeca
incomplete metamorphosis
labium
labrum
larva
Malpighian tubules
mandible
maxilla
mesothorax
metathorax
nymph
optic lobes
Orthoptera
ovipositor
palpus
prothorax
pupa
rectum
salivary glands
simple eye
spiracles
tarsus
tibia
trachea
trochanter
tympanum

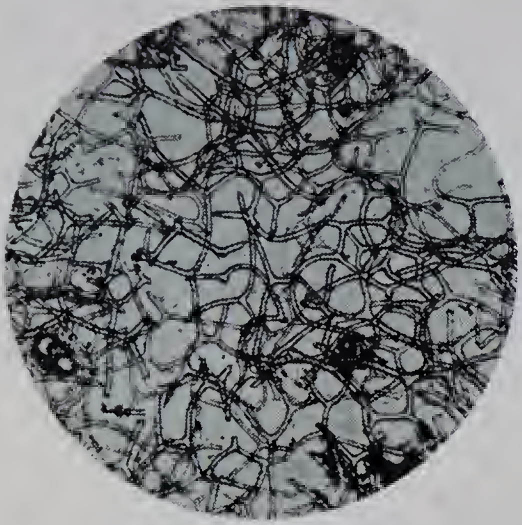
QUESTIONS FOR REVIEW

1. What characteristics of the grasshopper make it similar to the crayfish?
2. List the characteristics of the grasshopper that relate it to the insects.
3. Most animals have sense organs located on the head. In what respect is the grasshopper an exception to this rule?
4. How do the grasshopper's legs illustrate adaptation?
5. What are the eight body systems of the grasshopper and their function?
6. What is the chief difference between the blood system of the grasshopper and that of man?
7. What is the chief difference between the respiratory system of the grasshopper and that of man?
8. What kind of metamorphosis does the grasshopper undergo? What happens during this metamorphosis?
9. What protection is given the eggs of the grasshopper during the winter?
10. Which grasshopper relative is considered to be a useful animal? Why?

APPLYING PRINCIPLES AND CONCEPTS

1. What reasons can you give for the insects' being able to withstand unusual temperatures, pressures, and other environmental conditions?
2. Give reasons to support the statement, "Insects are the most successful creatures in the world."
3. What advantages are there to an insect in having complete metamorphosis?

CHAPTER 32



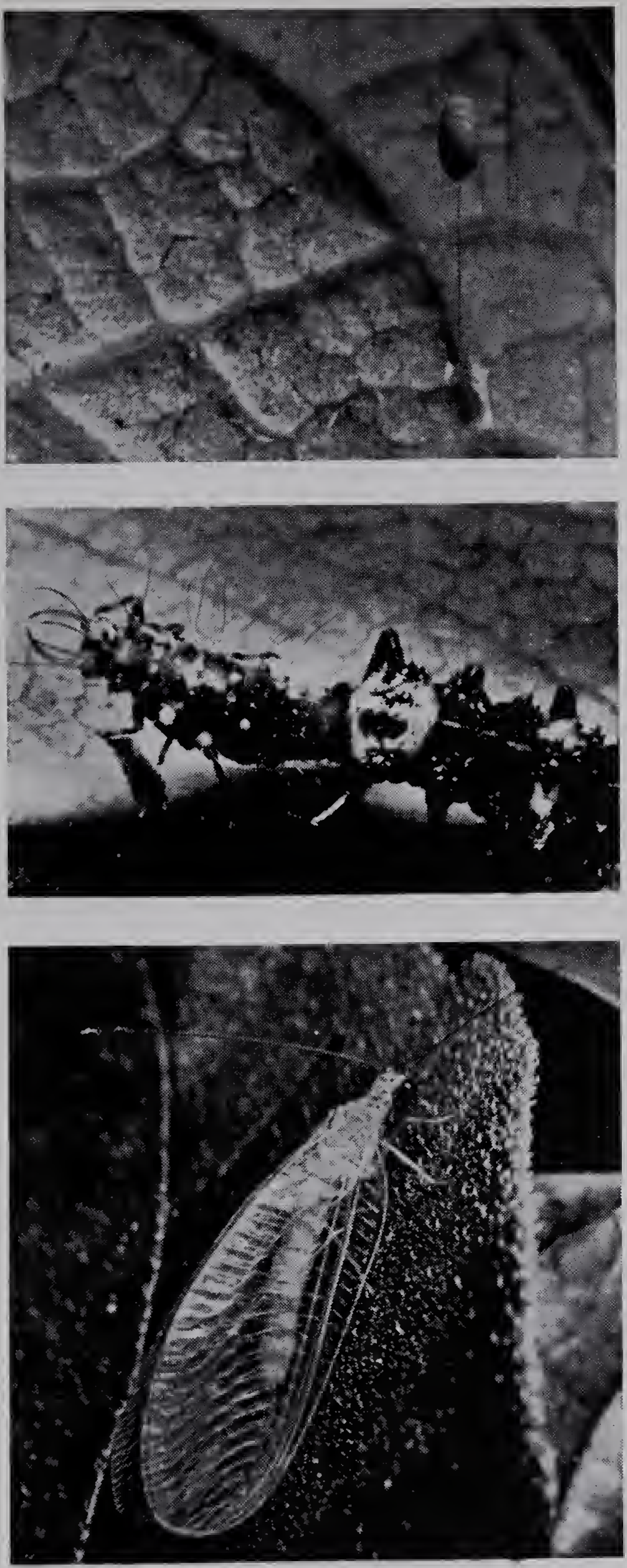
INSECT DIVERSITY

A lesson in adaptation. Insects have become adapted to a terrestrial life in numerous ways. The success of the Insecta can be attributed in part to a behavior much more complicated than the lower invertebrates that we discussed in previous chapters. The complicated behavior has been possible because of three major lines of development: 1. *complex sense organs;* 2. *jointed appendages;* and 3. a *brain.* The sense organs receive many kinds of stimuli from the immediate environment as well as from some distance away. These stimuli aid the animal in escaping enemies, finding food, finding a mate, and locating a suitable place for the development of eggs. The modification of jointed appendages into complex mouthparts is another important diversity of this class. Thus, insects have been able to utilize many different kinds of foods. The brain is complex enough to allow the insect to integrate impressions from the sense organs and utilize it in coordinated muscular responses.

With the development of these systems the insects are able to perform complicated, coordinated acts. They are able to modify their environment by building many kinds of homes and nests. The paper wasp builds nests of chewed woodpulp; the mud-dauber uses mud; the tarantula hawk (a large wasp) digs a burrow and stocks it with food for the carnivorous larvae. Some ants store grain in special passages made for this purpose. The fungus ant has regular underground gardens of a certain species of fungus that are tended by specialized workers. Before the ant queen takes off on her nuptial flight, she stores some of this fungus in a special pouch in her mouth so that she can start the culture in a new home.

As you will see, many insects form societies in which morphological diversity within the species allows for division of labor. Some are adapted for gathering food, some for protection of the home, some for tending the young, and some for reproduction. Such insects, which include the bees, ants, wasps, and termites, are called ***social insects.*** The activities of the social insects are not planned and thought about by the individuals performing the tasks. These animals perform their life duties by instinct. That is, they have specialized structures that are used in a behavior pattern that is not taught to them. Animal behavior studies form an interesting field of current research.

Insect diversity. Since there are so many insects, we will not be able to study them all. We can, however, look at the common orders and learn to recognize the characteristics that are used in their classification. These charac-



32-1 The egg of a lacewing, its larva being preyed upon by another larva, and the adult lacewing. This insect is carnivorous and cannabalistic. (Walter Dawn)

teristics include types of mouthparts, types of wings, and types of metamorphosis. Insects are commonly divided into a number of orders varying from 22 to 26. The difference in the number of orders is that some entomologists group two or more orders into one. The table on page 444 lists ten of the most common ones found in the temperate regions.

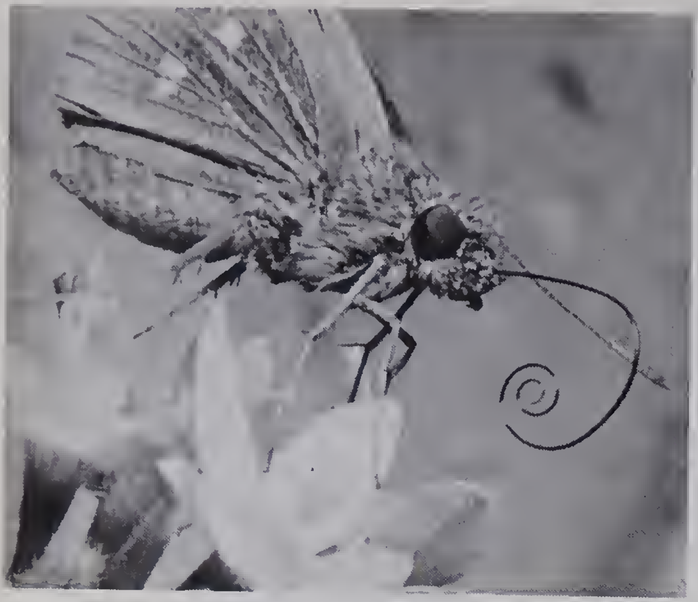
You can easily find insects in your home, in your school, outside in fields and ponds or trees, under stones, and hiding on plants with almost perfect camouflage. A particularly valuable project is to make your own insect collection. There is no better way to get to know the insects firsthand.

The order Lepidoptera. Butterflies and moths belong to the order ***Lepidoptera*** (lep-i-*dahp*-ter-a), which means "scale-winged." Their brilliant colors are due to microscopic scales on their wings, which make a mosaic pattern. If you handle living moths and butterflies, be sure to hold them by the thorax and with only light pressure of the fingers. Even a light touch on the wings will remove some scales and injure the insect for flight.

Most people confuse butterflies and moths. If you look at the table on page 435, you will see that it is not difficult to distinguish between them.

Head of a butterfly or moth. Unlike the grasshopper, the head of a butterfly or moth is hairy, often even shaggy, because of the presence of scales. The eyes are compound and large and rounded, and the neck is flexible. The mouthparts are different from those of the Orthoptera because they are adapted for sucking nectar from flowers. The maxillae are enormously lengthened and locked together to form the coiled *proboscis.* When extended it may equal all the rest of the body in length, and is thus able to reach the nectar glands of the flowers these insects visit.

In most Lepidoptera the labium is reduced in size to two feathery palpi.



32-2 Head of a butterfly. Notice the coiled proboscis and the lance-shaped antenna. (Annan Photo Features)

These mouthparts are homologous to those of the grasshopper, but they are adapted for different functions.

The thoracic and abdominal regions. The legs of the Lepidoptera are small and weak but have the same general structure as all insects' legs. Obviously the butterfly spends much of its time in the air and uses its legs only for clinging to some surface. The wings are large; the colored scales help the few veins in giving strength to the wing, and in some moths and butterflies aid in protective coloration. The butterfly, though easily supported by its large wingspread, is not a swift flier.

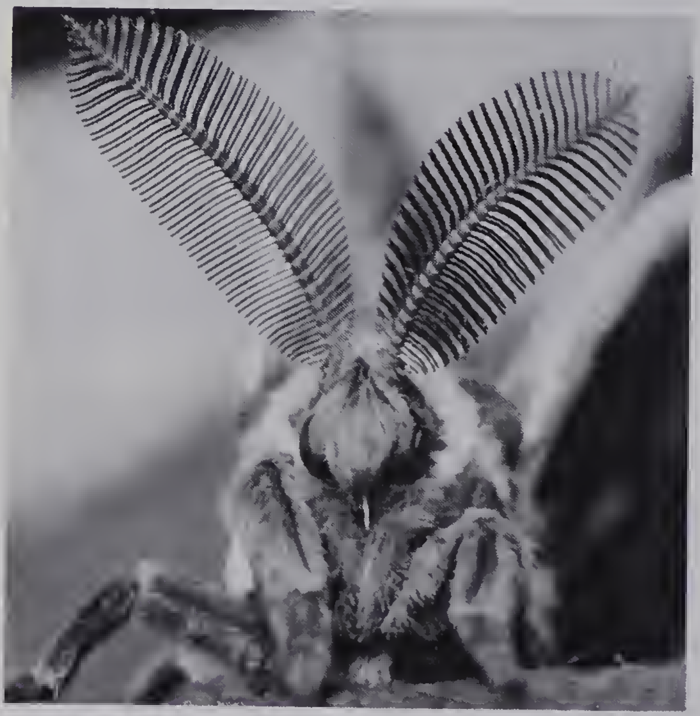
The abdomen resembles that of the grasshopper but has fewer visible segments, and, as in all insects, is the least specialized body region.

Life history of butterflies and moths. Most Lepidoptera deposit their eggs on or near the material which is to be the food of the young. Some eggs pass the winter in this stage, but usually eggs are deposited in the spring and develop into caterpillars the following summer.

Since the Lepidoptera undergo complete metamorphosis, the egg does not hatch into a form anything like the adult. Instead it produces the larval form called a ***caterpillar,*** with biting mouthparts. The caterpillar has three pairs of legs and some extra pairs of fleshy legs at the end of the abdomen. It eats ravenously, grows big and fat, and molts several times. Because the caterpillar needs tremendous amounts of food to keep up this rapid growth, it is during this stage that the insect does extensive damage.

When full grown, the caterpillar usually seeks a sheltered spot, hangs with its head down, and becomes very quiet. The body shortens and thickens; the exoskeleton splits down the back and is shed; and the animal now becomes a pupa. The butterfly pupa rests in a hardened case, often brown in color. It is then called a ***chrysalis*** (*kris*-a-lis). The moth larva usually spins a strong case of silk, the ***cocoon.***

The Lepidoptera usually spend the winter in the pupal stage. In the spring the insect emerges, totally changed, as the adult butterfly or moth.



32-3 Head of a moth. Compare the antenna of this insect with that of the butterfly. (Charles Walcott)

Notice that in a life history such as that of the Lepidoptera, the larval form has completely different mouthparts and therefore a completely different diet from that of the parents. The butterfly larva feed on leaves, while the adult sucks nectar from flowers. A life history such as this allows an insect a varied diet during its life and an abundant supply of usable food during its period of most rapid growth. The adult serves the species only in a reproductive manner to continue and disperse the species. There is no competition between the young and adult for food.

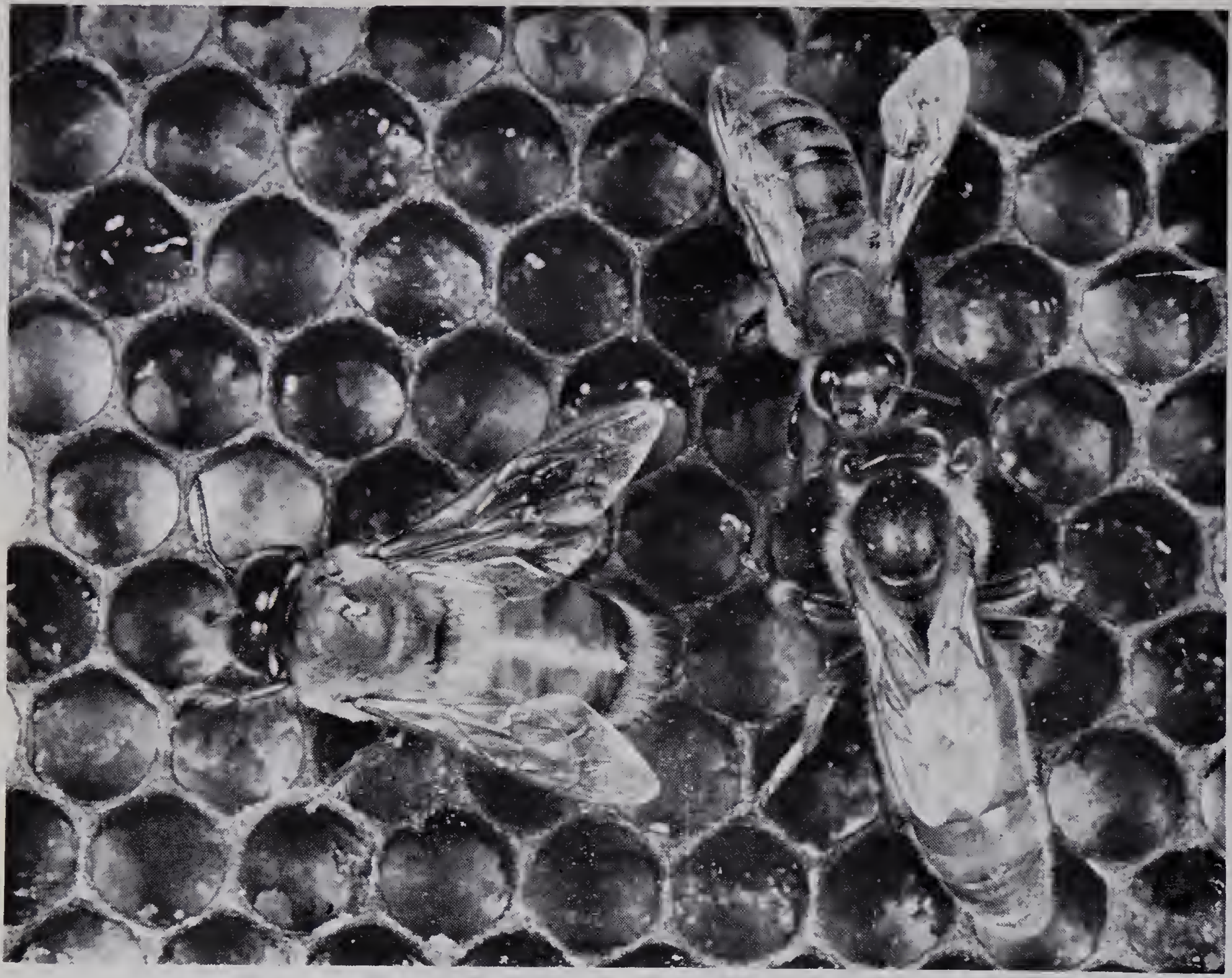
The social insects. The order ***Hymenoptera*** includes the social insects such as the ants, wasps, and bees, but it includes numerous solitary forms as well. Members of this order are characterized by two pairs of membranous wings (if wings are present). This characteristic gives the order its name, which means "membrane-winged." The Hymenoptera also have biting or sucking mouthparts, complete metamorphosis, and a definite constriction between the thorax and the abdomen.

32-4 The termite belongs to the order Isoptera and although its damage to wooden buildings is great, it is a social insect. (Hugh Spencer)

The honeybee, a living powerhouse. Many of you may water-ski. Have you ever been towed by a boat with an underpowered engine? It will drag you through the water, but even with the planing surfaces of your skis at a sharp angle, you cannot get up. If a jet airplane, with its heavy body and short wings, were underpowered it would not be able to get up either. The power and speed in both the skis and the jet are able to create the lift. If you examine a honeybee, you will see that it has very small wings in comparison with the size of the body. The anterior wings are larger. Tiny hooks may attach the posterior wings to the anterior ones. A first examination of the bee might lead to the conclusion that this insect could not possibly fly because its wings are too small for its body. Might you not conclude the same thing if you saw a prepared water skier on the beach or a jet airplane on the ground? The bee makes up for its large body size and short wings by having powerful muscles in the large thorax. These mus-

COMPARISON OF BUTTERFLY AND MOTH

Butterfly	*Moth*
Flies during the day	Generally flies in the dark
Pupa in chrysalis	Pupa in cocoon
Wings vertical when at rest	Wings held horizontally
Antennae knobbed	Antennae feathery
Abdomen slender	Abdomen stout



32-5 The large bee on the left, doing nothing, is a drone. The long, slender bee with wings folded is the queen. The smallest bee, the worker, is dutifully feeding the queen. (Annan Photo Features)

cles enable the wings to move at a high speed, producing the familiar hum, and making the bee a swift and enduring flier.

The queen is the mother of the colony. Perhaps nowhere else in the animal kingdom is individual variation and division of labor more noticeable than in the Hymenoptera. Variation has brought about three distinct forms: the queen, the drone, and the worker (Fig. 32–5). The *queen,* which is nearly twice as large as a worker, develops from the special treatment of a fertile egg. Workers enlarge a wax cell in which the egg is to grow, and when the grublike larva hatches, feed it with extra portions of a high-protein food they secrete called *royal jelly.* After five days the larva spins a silken cocoon, changes to a pupa, and is sealed in a large waxen chamber by the workers. When the mature queen emerges from her cell, she seeks out other queen larvae in the colony and kills them; or if she finds another adult queen, they fight until one is killed. She never uses her sting except against another queen. If the workers prevent the queen from destroying the other queens, she leaves the hive, taking with her from 2,000 to 20,000 bees to seek a new home. By this swarming new colonies are formed and overcrowding is prevented.

After a few days the queen takes a wedding flight up into the air where she mates with a drone (male bee), receiving several million sperm cells. Then she returns to the hive and begins her lifework of laying eggs. This is no small task as one queen may produce as many as one million eggs per year and often lives from five to ten years. Although we call her a queen, she is in no sense the ruler of the hive, but rather its common mother.

The male bee. The ***drones,*** while larger than the workers, are smaller than the queen and have a thick, broad body, enormous eyes, and very powerful wings. They develop from unfertilized eggs. Their tongues are not long enough to obtain nectar, so they have to be fed by the workers. During the summer a few hundred drones are tolerated in the colony, because one of them must function as a mate for the new queen. The rest are of no use in the hive. This easy life has its troubles, however. With the coming of the autumn, when honey runs low, the workers will no longer support the drones, and starve them or sting them to death. Their bodies may often be found around the hives in the early autumn.

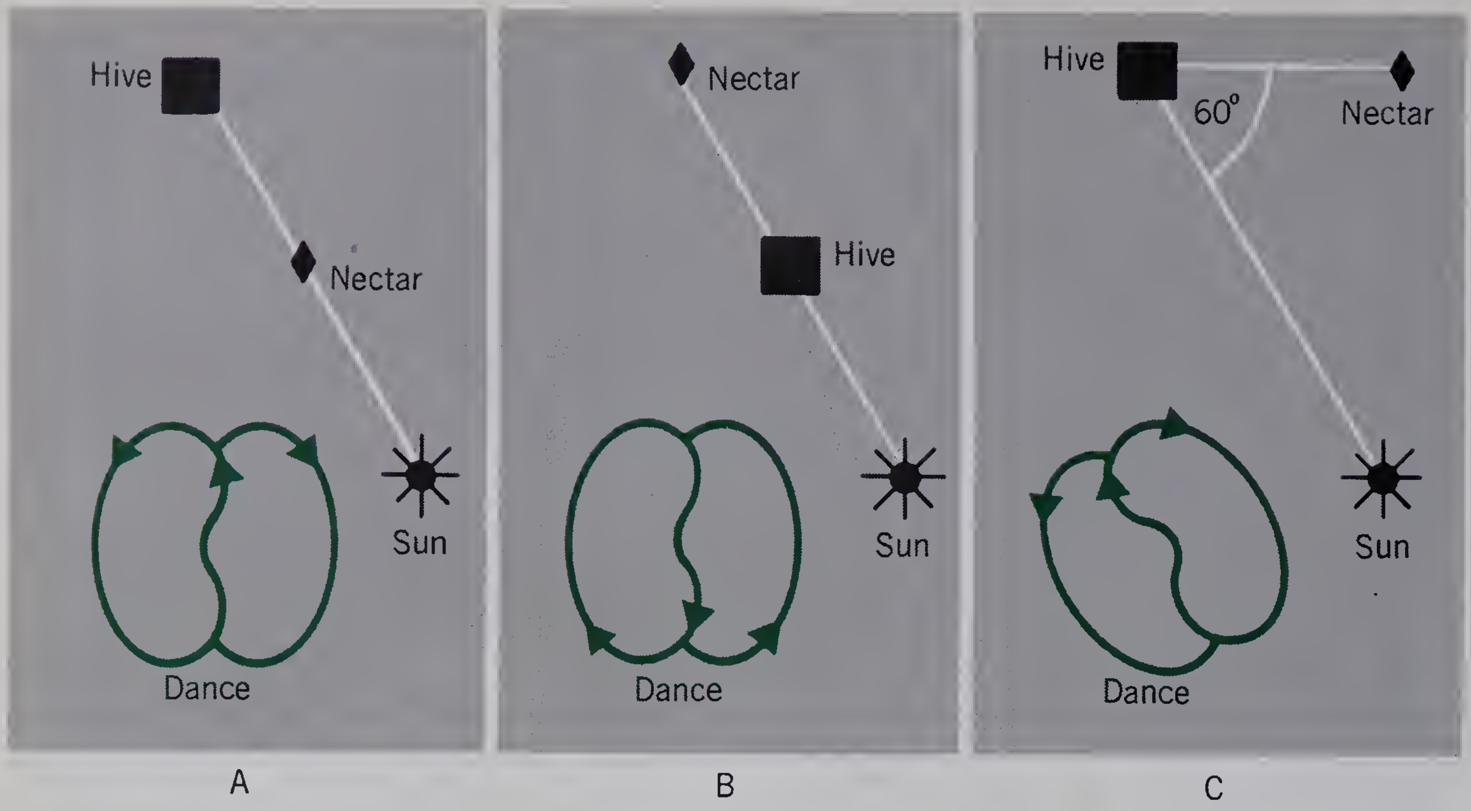
The worker bees. The ***workers*** are by far the most numerous inhabitants of the hive. They are undeveloped females, smaller than drones, and with the ovipositor modified into a sting. This is a complicated organ consisting of two barbed darts operated by strong muscles and enclosed in a sheath. The darts are connected with a gland that secretes the poison that makes a bee sting painful. With the exception of reproduction, all the varied industries and products of the hive are the business of the worker. They attend and feed the queen and drones. They act as nurses to the hungry larvae, feeding them with partly digested food from their own stomachs. Workers clean the hive of dead bees or foreign matter, and they fan with their wings to ventilate the hive. All the time thousands of workers are bringing in nectar and pollen as needed for the use of the colony. In summer the workers literally work themselves to death in three or four weeks, but bees hatched in the fall may live six months.

The worker has numerous specialized structures that adapt her for her tasks. The labium and maxilla together form an efficient lapping tongue for gathering nectar. On the four last abdominal segments are glands that secrete the wax used in comb-making. The legs have various specialized structures such as an antenna cleaner, pollen packer, pollen basket, and pollen comb.

The structure and products of the hive. The comb is a wonderful structure composed of six-sided cells in two layers. It is so arranged as to leave no waste space, and to afford the greatest storage capacity using the least material. Honey and *beebread,* a food substance made by the worker from pollen and saliva, is stored in the cells of the comb. In a section of the hive called the *brood comb,* the queen places one egg in each cell.

Honey is made from the nectar of flowers that is taken into the crop of the bee. Here the sugars are changed to a more easily digestible form which is then emptied into the comb cells. In these, the honey is left to thicken by evaporation before the cell is sealed. The removal of honey by man does not harm the bees if enough is left for their winter use. About 30 pounds are enough to feed an average colony of 40,000 bees for an ordinary winter.

The language of the bees. One recent discovery indicates that bees communi-



32-6 A. The dancing bee makes the diameter of the "round dance" upward on the vertical surface of the comb. This indicates to the other bees that a source of nectar is located in a direction toward the sun. B. This dance indicates that the nectar is located in a direction away from the sun. C. Decipher this message.

cate with one another by a complicated set of dances. When a worker returns to the hive, she can inform the other workers of the distance, direction, type, and amount of nectar available. To do this she dances on the vertical surface of the comb. The dance consists of a series of circles, with the bee making a path through a diameter of the circle each time she passes around one circumference (Fig. 32–6). The direction of the diameter indicates the direction of the nectar source in relation to the sun. If the food source is directly toward or away from the sun, in relation to the hive, the diameter of the circle is in a line perpendicular to the horizon. The dancing worker indicates a direction toward the sun if she traces the diameter while moving up, and thus away from gravity. Forming the diameter while moving down indicates that the food source is in a direction away from the sun. If the food is 60 degrees to the left of the sun's direction, the diameter traced is 60 degrees to the left of the vertical, and so on. Notice that this is all the more remarkable because the dancing bee is transposing the angle between the direction of the sun and that of the food source to a vertical angle with respect to gravity.

As the other workers gather around the dancing bee, they obtain the information about the direction of a food source. The type of food is determined by smell. The distance of the food is determined by the number of times the bee waggles her body while tracing the diameter of the circle. The greater the amount of nectar available, the more vigorous is her dance.

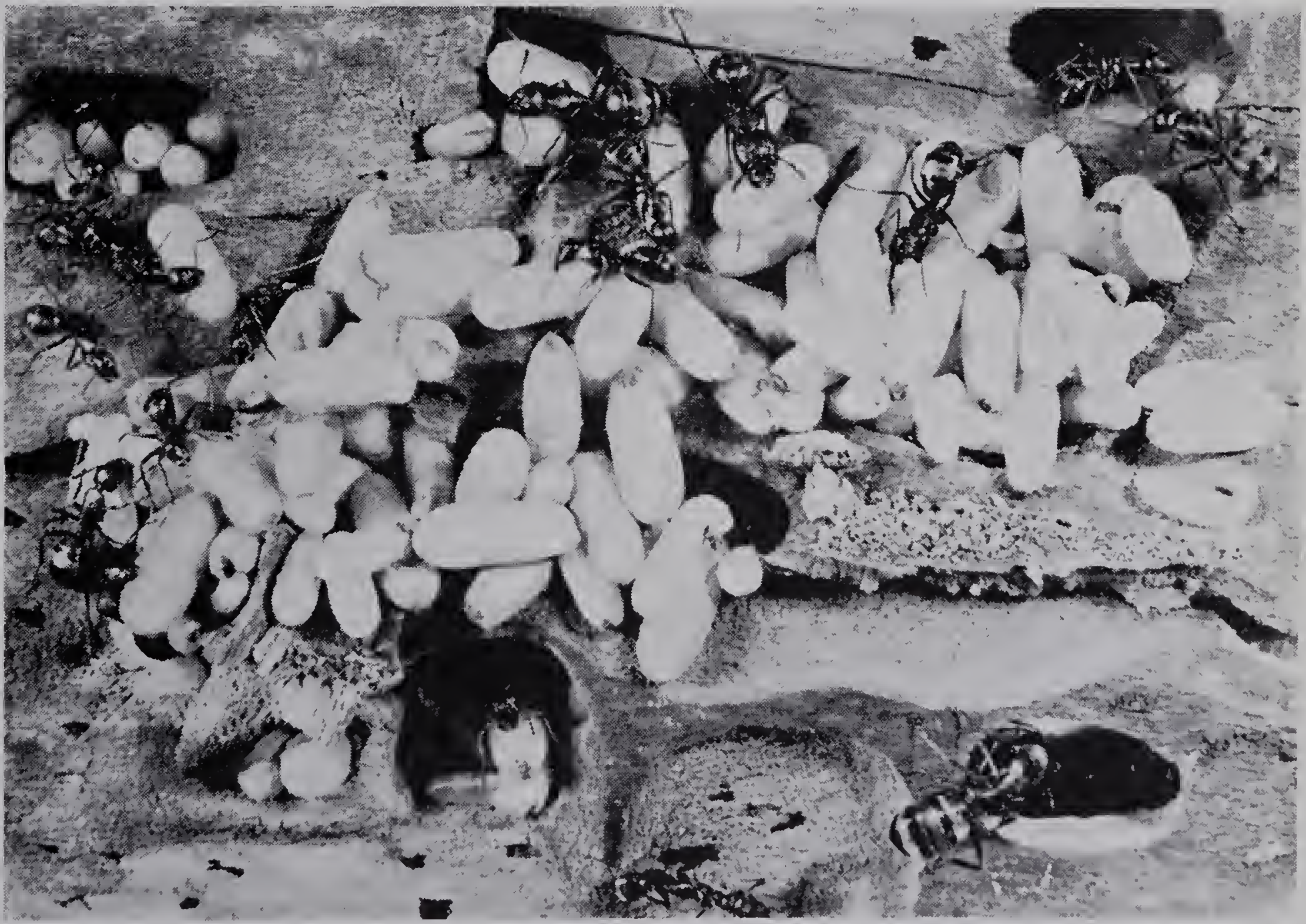
Other Hymenoptera. Like the bees, ants are social insects and the colony requires a queen. Unlike the bees, most ants cannot sting, but they bite with jaws more powerful in proportion to their size than those of any other insects. It is an interesting and generally unknown fact that during the early autumn, males and females will develop wings and so are able to fly out to start new colonies.

Wasps, both solitary and social, and hornets, are interesting not only because of the personal experiences we may have had with their stings, but because some of them are probably the original papermakers of the world. Their nests are made from a sort of pulp obtained from strips of wood chewed vigorously and mixed with secretions from the mouth.

Although the tiny ichneumon fly usually goes unnoticed, it is very valuable to us. These small insects lay their eggs under the skin of living caterpillars. When the larvae hatch they fed on the tissues of the host, and by the time they pupate the caterpillar is dead.

The order Isoptera. Termites belong to the order ***Isoptera,*** which means "same-winged," as they generally have two pairs of similar wings. These social insects are often thought of as harmful because they destroy buildings, but as you will see in Unit Eight, they also perform an important function in the forests by returning minerals to the soil.

Cellulose is a polysaccharide found in the cell walls of plants, and is completely indigestible by most animals. In termites, however, an interesting association exists. The protozoan *Tricho-*



32-7 An old dried log has been opened to expose the home of carpenter ants. Note the many runways and storehouses in which larvae and cocoons are safely protected. (Chace from National Audubon Society) *nympha* lives in their digestive tracts. This protozoan produces an enzyme that is capable of breaking down cellulose. The termite provides *Trichonympha* with bits of wood and a place to live. In turn the protist provides the termite with digested cellulose, without which the termite could not live.

The insect order Odonata. The name of the order ***Odonata*** (o'*hd*-n-ah-ta) comes from a Greek word meaning "tooth." It is probable that the larval stage of these insects is responsible for their name. The larva lives in streams where it preys on the larvae of many other insects. It catches them by rapidly extending its elongated labium. To some perhaps this lower lip resembled a big tooth that shoots out to catch prey. The wings of the Odonata are membranous and do not overlap. At rest they are held at right angles to the body. The abdomen is long, but there is no stalk connecting it to the thorax. These insects, exemplified by the dragonfly and damsel fly, are very beneficial. Not only are they predators when in the larval stage, but even as adults they fly over water, catching mosquitoes, gnats, and other small insects.

The beetles. About 250,000 species of beetles have been recorded, and most of them can be easily recognized as beetles because of their hard forewings which fit closely over the body and resemble a shell. They all have strong jaws and undergo complete metamorphosis; they belong to the order ***Coleoptera*** (koh-lee-*ahp*-ter-a), which means "sheath-winged."

Wood-boring beetles cause extensive losses; buffalo bugs are destructive to carpets and furs; potato beetles ravage gardens; weevils damage grain and cotton. Texas alone has paid more than $150,000,000 in attempting to control the boll weevil. The Japanese beetle, first discovered in this country in New Jersey in 1916, has already become a great menace to fruit trees and other crops. Carrion beetles, on the other hand, are scavengers; ladybugs eat scale insects and thus aid the citrus fruit industry; and Calosoma beetles have been introduced into New England and elsewhere to help control the gypsy moth.

The order Hemiptera includes many pests. The "half-winged" insects have sucking mouthparts and undergo incomplete metamorphosis. The edges of their wings overlap, and only half of the wing is thickened. One or two forms are wingless. The insects belonging to the order ***Hemiptera*** (hi-*mip*-ter-a) are the only insects constituting the true bugs. Among them are many of our worst pests, such as the chinch bug, bedbug, squash bug, and stinkbug. Others, less harmful to us, include aquatic insects such as water striders, backswimmers, water boatmen, and water bugs.

The order Homoptera. Though some of the members of the order ***Homoptera*** (hoh-*mahp*-ter-a) are wingless, the name means "similar wings." When wings are present they are held over the body in an inverted V, like the roof of a house. All have sucking mouthparts and undergo incomplete metamorphosis. Plant lice, scale insects, mealy bugs, leaf hoppers, and others take a huge toll of our wild and cultivated plants. We are indebted, however, to the lac insect, which alone of the Homoptera is of economic benefit. We get *shellac* from it, used throughout the world as a base for lacquer and wood finishes.

One species of cicada (si-*kayd*-a), a common representative of the Homop-

32-8 The housefly carries disease-causing organisms on the many hairs which cover its body. (USDA)

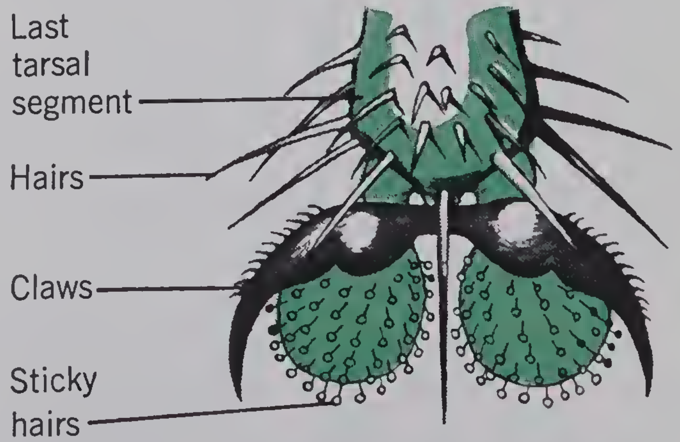
tera, lives underground for two years; another species, for 17 years. The cicadas then tunnel to the surface and spend a week or two as adults. Their high-pitched and strident notes, coming from the treetops, are familiar on hot summer evenings.

The Neuroptera. On warm summer evenings in most parts of the United States, lacewings can be seen fluttering about. Their four delicate wings are green and transparent. The veining of the wings gives a network appearance so that the name ***Neuroptera*** (n(y)u-*rahp*-ter-a), which means "nerve-winged," seems appropriate. The lacewings have long antennae and golden-colored eyes. As larvae and adults they have chewing mouthparts and an appetite for aphids, which is why they are also called aphis lions.

The two-winged insects. The insects of the order ***Diptera*** have only two wings. They have mouthparts suited for piercing, rasping, and sucking. Their metamorphosis is complete. This order includes the mosquitoes, which are known for their annoying habits as well as their disease-carrying characteristics. The tsetse fly of Africa, responsible for the transmission of the protozoan-caused sleeping sickness, and the common housefly also belong to this order.

One of our most notorious enemies in the insect world is the housefly. Because it breeds in filth, the housefly often infects people with typhoid, dysentery, and other filth-borne diseases. The housefly has large eyes, short, fleshy antennae, and a club-shaped sucking tube. It never bites, but the related stable fly, or horsefly, bites cattle and man. The wings of the housefly are well developed and operate at high speed because of the powerful muscles of the thorax. The six legs are also well developed, and the feet have claws and sticky hairs that aid in clinging (Fig. 32–9). Unless these hair tips are free from dust, they do not stick well and the fly cannot walk easily on smooth surfaces. You have probably noticed the care with which a fly cleans its feet by constantly rubbing them against each other.

About 200 eggs are deposited in horse manure or in similar matter by the female. They hatch in one day into the larval form called ***maggots***, and in this stage do some good as scavengers. After eating and growing for five or six



32-9 This enlarged drawing of the foot of the housefly shows the projections and sticky hairs which make it possible for the insect to carry filth.

REPRODUCTION OF FLIES

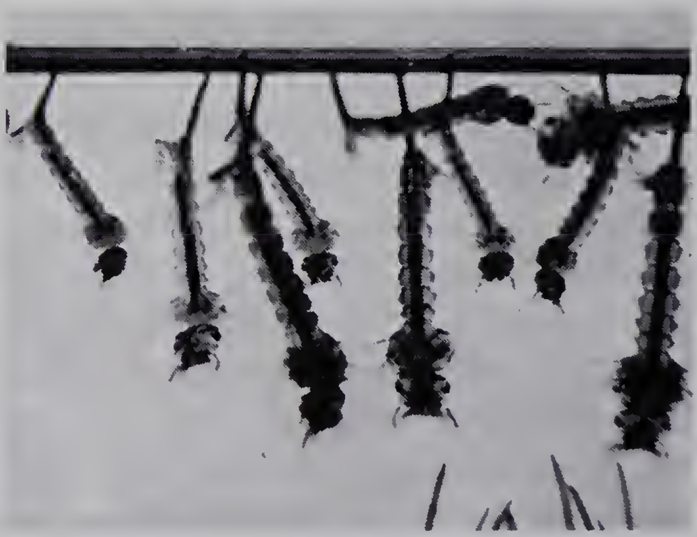
1st	generation	(eggs that hatch from first female)	200	(100 females)
2nd	"	(100 females × 200 eggs each)	20,000	(10,000 females)
3rd	"	(10,000 × 200)	2,000,000	
4th	"		200,000,000	
5th	"		20,000,000,000	
6th	"		2,000,000,000,000	
			2,020,202,020,200	in 12 weeks

days, the larvae pass into the pupal condition, inside the last larval skin, which thus takes the place of a cocoon. From this stage adults emerge in about a week. The whole development from egg to adult takes about two weeks. Breeding begins early in spring and continues until the cold weather starts. Flies multiply at a tremendous rate. If reproduction were unchecked and all offspring survived (which fortunately is not the case), one fly laying 200 eggs would result in 2,020,202,020,200 flies in 12 weeks, as shown in the table above.

The mosquito. In the mosquito the mouthparts — labrum, tongue, mandibles, and maxillae — are reduced to sharp lancelike bristles. They are enclosed in the labium, which serves as a sheath, and are ideally suited for piercing and sucking. In order to dilute human blood so that they can withdraw it and prevent it from clotting in the proboscis, they inject a little saliva. This causes the irritation and swelling we call a mosquito bite.

The female usually lays her eggs in water. Ponds, rain barrels, and even tin cans furnish ideal breeding places. The eggs are deposited as single eggs or in tiny rafts consisting of many eggs covered with a waterproof coating. The mosquito larva, called a ***wiggler,*** breathes air, which it obtains through a tube projecting from the posterior of its abdomen. Often it can be seen with this tube at the surface and the body hanging head downward in the water (Fig. 32–10).

The pupal stage is also passed in the water; it differs from most insect pupae in that it is active like the larva. The adult emerges from the pupa, whose shed skin acts as a raft. At this critical time the mosquito must not fall overboard or get its wings wet before they expand, or it will die. There are exceptions to this description, but it pertains to most mosquitoes.



32-10 These larvae of the *Culex* mosquito obtain oxygen by means of a breathing tube which penetrates the surface of the water. (Hugh Spencer)

Our most common northern mosquito, *Culex*, occasionally carries encephalitis, a form of sleeping sickness. *Anopheles* (a-*nahf*-e-leez) carries the protozoan *Plasmodium*, which causes malaria. *Culex* may be distinguished from *Anopheles* by the fact that the latter stands almost on its head when at rest, while *Culex* holds its body more nearly horizontal. *Aëdes* (ay-*eed*-eez), the mosquito that carries the virus of yellow fever, is a tropical species and does not usually invade our temperate regions.

The economic importance of insects. Probably only a minority of insects are distinctly detrimental to man. Yet these obnoxious forms are so prominent and well known that popular opinion is apt to condemn all insects. Coping with animals as numerous and active as insects requires accurate knowledge of their habits and life histories.

Their harmful activities are to:

1. Destroy grain, vegetables, and fruit (numerous species).
2. Injure shade trees (tussock, gypsy, and leopard moths).
3. Carry disease germs to animals and man (fleas, lice, flies, mosquitoes).
4. Act as agents in the spread of plant diseases (grasshoppers and aphids).
5. Destroy buildings and wood (beetles, ants, termites).
6. Annoy and injure by bites and stings (wasps, mosquitoes, gnats).
7. Affect food (beetles, cockroaches).
8. Destroy clothing and fabrics (clothes moths, carpet beetles).
9. Act as parasites on domestic animals and man (botflies, fleas, lice).

On the other hand, we owe to insects useful processes and products such as the following:

1. Pollinating of flowers (bees, butterflies, moths, certain types of flies).
2. Making silk (silk moth cocoon).
3. Furnishing of honey and wax (bees).
4. Furnishing of shellac (lac insect).
5. Supplying dye (cochineal insect).
6. Furnishing of material for ink (gall insects).
7. Acting as scavengers (maggots, beetles).
8. Killing of injurious insects (ladybugs, ichneumon flies).

The control of insect pests. While most other forms of life have been unable to maintain their numbers with the spread of human civilization, insects have continued to be a dominant form of animal life. As you have learned in your study of insects, their small size, adaptability, and rapid rate of reproduction have allowed them to become, with man, the most biologically successful form of life. Since many insects carry disease or destroy man's crops and stored foods, control of them is a constant concern. The war against insects is fought with three principal weapons: *quarantine, chemical control,* and *biological control.*

The first weapon is administered by the Bureau of Entomology and Plant Quarantine operating under the U.S. Department of Agriculture. Quarantine became necessary because at least 75 species of harmful insects have been introduced into this country in the form of eggs or larvae concealed on plants or in fresh fruits. Today inspectors in every port of entry confiscate harmful insects or fungus pests. Quarantine has also been used by many state governments to help prevent widespread insect destruction.

If quarantines had been in operation earlier in our history, we might not be struggling today with the European corn borer, the Mexican bean beetle, the Japanese beetle, the Oriental peach moth, the gypsy moth, the cotton boll

SUMMARY OF CHARACTERISTICS OF INSECT ORDERS

Order	*Metamorphosis*	*Mouthparts in Adult*	*Economic Importance of Some*	*Examples*
ORTHOPTERA ("straight-winged")	Incomplete	Chewing	Damage crops, act as pests	Grasshoppers, crickets, katydids, locusts, cockroaches
LEPIDOPTERA ("scale-winged")	Complete	Siphoning	Pollinate flowers, produce silk, damage clothing and crops	Butterflies, moths
HYMENOPTERA ("membrane-winged")	Complete	Biting or sucking	Pollinate flowers, act as pests, parasitize other pests, make honey	Bees, wasps, ants
ISOPTERA ("same-winged")	Incomplete	Chewing	Destroy buildings	Termites
ODONATA ("toothed")	Incomplete	Biting	Destroy harmful insects	Dragonflies, damsel flies
COLEOPTERA ("sheath-winged")	Complete	Sucking or chewing	Destroy crops, act as pests, prey on other insects	Weevils, ladybirds, ground beetles
HEMIPTERA ("half-winged")	Incomplete	Sucking	Damage plants, act as pests, carry disease	Squash bugs, all true bugs
HOMOPTERA ("like-winged")	Incomplete	Sucking	Damage crops and gardens	Aphids, mealy bugs, cicada, scale insects
NEUROPTERA ("nerve-winged")	Complete	Chewing	Destroy harmful insects	Dobson fly, aphis lion
DIPTERA ("two-winged")	Complete	Sucking or chewing	Carry disease, act as pests	Flies, mosquitoes

weevil, and many other foreign insect pests.

Chemical control. Chemical poisons used to kill insects are called ***insecticides***, which means, literally, "insect killers." Although expensive, chemical control has been considered the most effective method of reducing insect populations. *Stomach poisons* are used on chewing insects such as beetles, grasshoppers, and caterpillars. The poison is consumed as the insect eats the leaves of the plant. Some insects, such as true bugs, aphids, lice, and scale insects, get their food by sucking plant juices. A thin coat of poison on the leaf does not bother them as they push their beaks through it. The insecticides used against these pests are called *contact poisons*. Many of these chemicals act by clogging or poisoning the tracheae of insects, causing them to suffocate.

DDT, a chemical insecticide. The field of synthetic insecticides is best represented by DDT (which is short for *dichloro-diphenyl-trichloro-ethane*). DDT is not a recent discovery, although we have only used it extensively during the past ten or twelve years. It was first used effectively in World War II to control body lice and the malarial mosquito. Now we use it for fly and mosquito control as well as for general garden and farm insect control.

DDT is a contact poison available as powder and oil-solvent sprays. It is extremely potent against many kinds of insects, which it kills by its paralyzing effect on the nervous system. The chitin in the skeleton seems to attract and hold the DDT. Roaches, mosquitoes, and bedbugs succumb quickly in air containing DDT mist. Important agricultural uses of DDT include spraying of orchards and garden crops.

Both the powder and spray forms of DDT can be absorbed through the skin. Persons using it must take the greatest care and must see that none gets on any part of the body. Children and pets should never be allowed where it is being used.

Some disadvantages of chemical control. Although the wide use of insecticides has been of considerable value in controlling insect pests, many disadvantages are becoming more obvious. Through natural selection many insect strains have evolved that are resistant to the effects of a particular chemical. For example, successive generations of houseflies produced from survivors of DDT exposure have resulted in offspring resistant to the poison.

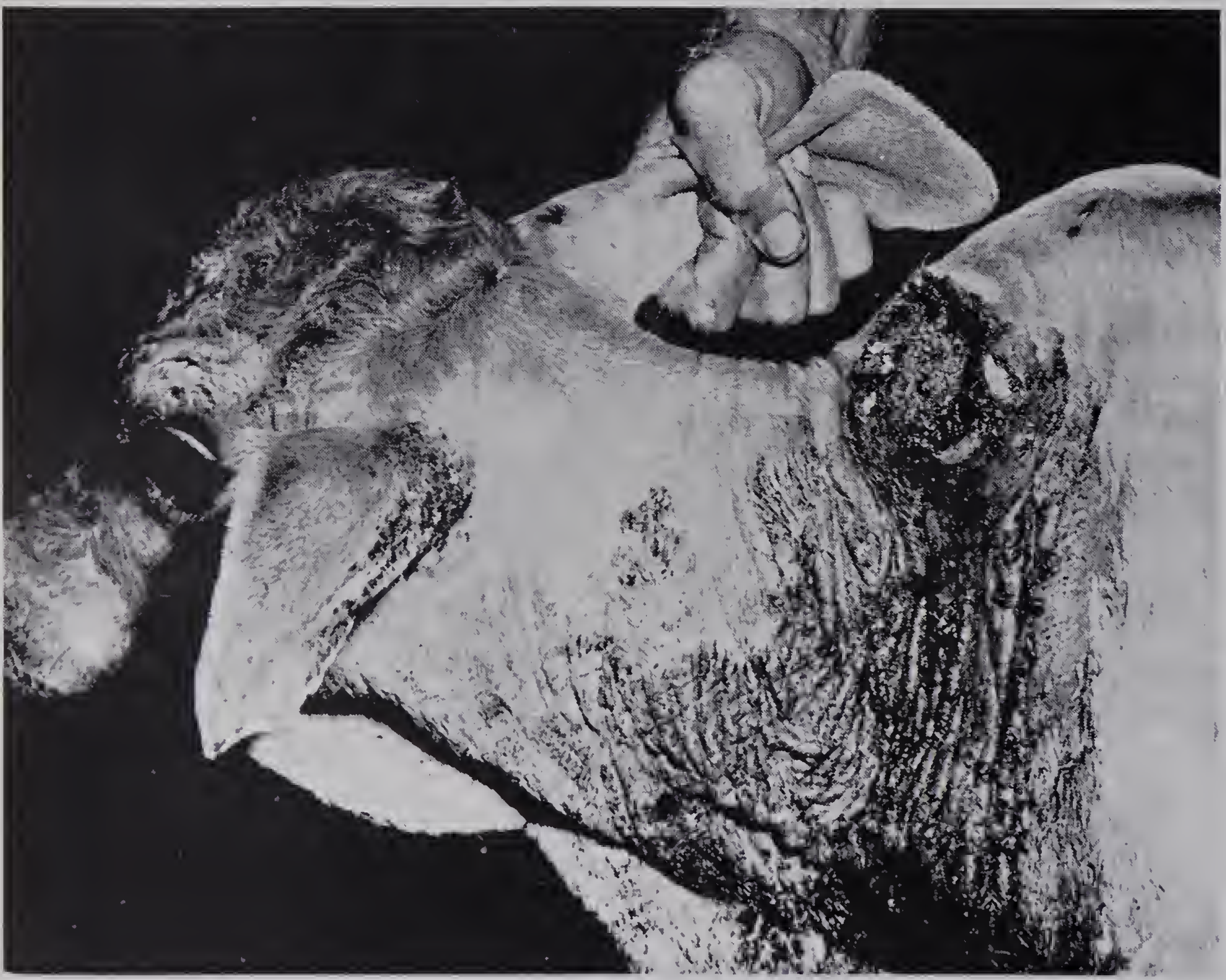
Destruction of natural insect enemies of pest insects is one of the most important and least recognized results of large-scale application of insecticides. Another is the accumulation of residues of these poisons in mammals and birds that feed on poisoned insects. This is the chief way that so many animals are affected — even those not sprayed or those that are fairly invulnerable when they are sprayed. But when they feed on insects or other animals containing DDT, the compound is stored up in the body fat and hence may accumulate to very high, and often lethal, levels.

In 1957 the larva of the gypsy moth was spreading in the New England states. Since the larvae of this moth eat leaves of oak and other hardwood trees, its extermination was considered desirable. DDT was sprayed from airplanes over New York and Long Island. Undoubtedly most of the gypsy moth larvae were killed, but so were a multitude of plants, birds, crabs, fish, beneficial insects, and mammals. Truck gardeners lost many crops, and even the milk from cows feeding on contaminated plants contained DDT and could not be sold.

Much of the damage from insecticides and many of the unexpected and tragic results might have been avoided had more attention been paid to the life cycles and interactions among plants and animals that you are now studying.

Biological control of insects. Since the widespread use of insecticides has so many disadvantages, entomologists are constantly seeking other methods of insect control. We shall group these methods under the general heading of biological controls, since they utilize insect relationships with one another and with their environment. Entomologists have known for a long time, for example, that many male moths are attracted to the female by a scent that is detectable for great distances. The scent from female gypsy moths has been used to lure males into traps where they are then killed by man. The lure scent has now been synthesized from castor oil. As little as 1/1000 gram proves to be an effective and economic lure. The search is continuing for similar attractants in other harmful organisms.

Natural enemies as biological controls. Perhaps you have wondered how, if Japanese beetles are so terribly destructive, the Japanese are able to raise any plants at all. The answer concerns natural en-



32-11 Eradication of such pests as the screwworm fly is possible only when owners of infested animals report on the situation in their herds. Here, eggs and larvae are being collected from an infested animal. (USDA) emies of insects. Insects were present in America before our ancestors arrived from other lands. Yet, even without any control measures, these insects were held in check by their natural enemies. The fact that our worst pests are imported species is also explained in terms of natural enemies. Introduced insects are free from those animals that held them in check in their native land. Consequently, they have multiplied here at a tremendous rate. Attempts have been made to import the natural enemies. Frequently, however, they also become pests, thus creating a still greater problem.

Birds are the most important natural enemies of insects. Much of our success in combating insects depends on conservation of our bird life. We still have not learned this lesson completely, for we needlessly destroy necessary nesting places and feeding grounds for our most important allies in the war on insects.

Snakes, frogs, spiders, and toads are other valuable natural enemies of the insect world. But our attitude toward these creatures is far from enlightened. How many of you have felt that you rendered a valuable service by killing a harmless garter snake, which lives largely on small rodents and insects?

Insect control by environmental changes. Man can control some insects by changing their environment. For instance, we can control certain insects by rotating crops in one area. This method is good for such localized pests as beetle grubs and others, but it is ineffective against those insects that migrate.

Another method is to drain those places where certain pests breed. Ditches, ponds, and various shallow bodies of water must be drained regularly to make it impossible for these insects to complete their life cycle. This is especially true of the mosquito. Drainage is a costly process, however, and often results in useless destruction of wildlife. The water loss also hurts mankind far more than the presence of mosquitoes, which are more cheaply controlled by other means.

Still another effective method of environmental control is to correct faulty methods of sewage disposal. Flies often breed in sewage. If modern disposal is practiced, the breeding places are destroyed.

Equally important is proper garbage disposal. Again, some insects breed in this type of filth; and the best way to prevent this breeding is to burn or treat garbage to be sure that none of it is dumped where insects can get at it. We should not forget man's mechanical methods of insect control, however. The flyswatter, traps, flypaper, and electric screens are still common ways of insect destruction.

Control by sterilization. Another successful method of insect control utilizes radiation. About 25 years ago Dr. Edward Knipling suggested sterilizing male insects of a given harmful species. He reasoned that, when released, the sterile males would compete with normal males. The females would then produce infertile eggs after mating with the sterile males. Since X rays have been known to cause sterilization in insects, Dr. Knipling proposed using this method. He chose the screwworm fly for his first experiment. The female fly of this insect lays her eggs in any open wound of a mammal. In the southern part of the United States, Texas, Mexico, Central America, and South America, the screwworm causes livestock losses estimated at many millions of dollars. Deer and other wildlife are also affected by these insects, which are capable of killing a full-grown steer in 10 days.

In 1954 Dr. Knipling began a test of his theory on the isolated island of Curaçao in the Caribbean. Male screwworm flies were raised and treated with X rays in Florida and then flown and released from airplanes in Curaçao. The number and fertility of egg masses on experimental goats decreased. Two months after weekly distribution of irradiated flies, all the eggs were infertile. The screwworm has been completely removed from Curaçao. From 1957 to 1959 similar treatment has eliminated the screwworm in Florida and parts of Alabama and Georgia. Quarantine methods are now used to prevent the insect re-entering from infected areas of the Southwest. Entomologists are now determining whether similar sterilization may be effective against other pests.

IN CONCLUSION

The great diversity in the structure of insects has allowed them to inhabit almost every environment, utilize a variety of foods, and to compete with man with considerable success. For these reasons insects are considered a biologically successful group.

Because insects transmit disease, consume man's crops and stored foods, and damage gardens, several control measures have been employed. In order to determine the most effective measures, however, the life history and habits of each pest must be known. Often when using effective methods for controlling one insect pest, we unwittingly destroy beneficial organisms or encourage other harmful pests.

Our next unit will discuss the familiar animals with backbones, and perhaps some that are not quite so familiar. As you read about the various vertebrates, compare them with the invertebrates you have just studied.

BIOLOGICALLY SPEAKING

caterpillar
chrysalis
cocoon
Coleoptera
Diptera
drone
Hemiptera
Homoptera
Hymenoptera
insecticide
Isoptera
Lepidoptera
maggot
Neuroptera
Odonata
proboscis
queen
social insects
wiggler
worker

QUESTIONS FOR REVIEW

1. In what ways have insects adapted to terrestrial life?
2. Why are the mouthparts of the butterfly homologous to the mouthparts of the grasshopper?
3. How are the Lepidoptera harmful in certain stages?
4. Many of the Hymenoptera may be considered well disciplined. Why is this trait often confused with intelligence?

5. Name the different types of bees and describe the functions of each in the hive.
6. Do bees communicate with one another in the hive? Explain.
7. How are the Neuroptera helpful to man?
8. Give the life history of the housefly.
9. In trying to eliminate mosquitoes, why is prevention better than cure?

APPLYING PRINCIPLES AND CONCEPTS

1. In what ways can insects modify their environment?
2. Discuss further experiments that might be performed to understand communication of the bees.
3. Biologists state that the army ant of the tropics is entirely blind. Name some other animals that lead successful lives in spite of the fact they are missing one or more of the senses of higher animals.
4. Can a little fly grow to be a large fly? Explain.
5. What stage in the development of the housefly is easiest to control? Why?

RELATED READING

Books

Bandsma, A. T. and Brandt, R. T. *The Amazing World of Insects.* The Macmillan Co., Chicago. 1963

Berrill, N. J. *The Living Tide.* Dodd, Mead and Co., New York. 1951

Borradaile, L. A. *The Invertebrata (3rd Ed.).* Cambridge University Press, New York. 1958

Buchsbaum, Ralph and Lorus J. Milne. *The Lower Animals: Living Invertebrates of the World.* Doubleday and Co., Garden City. 1960

Carson, Rachel. *The Edge of the Sea.* Houghton Mifflin Co., Boston. 1954

Chandler, Asa C. and Clark P. Reed. *Introduction to Parasitology (10th Ed.).* John Wiley and Sons, New York. 1961

Darwin, Charles. *Structure and Distribution of Coral Reefs.* University of California Press, Berkeley. 1962

Edmondson, W. T. (ed) *Ward and Whipple's Fresh-Water Biology.* John Wiley and Sons, New York. 1959

Emerton, James H. *The Common Spiders of the United States.* Dover, New York.

Farb, Peter. *The Insects.* Time, Inc., New York. 1964

Green, James. *A Biology of the Crustacea.* Quadrangle Books of Chicago. 1961

Guberlet, Muriel. *Explorers of the Sea: Famous Oceanographers.* Ronald Press, Co., New York. 1964

Hegner, Robert. *Parade of the Animal Kingdom.* The Macmillan Co., New York. 1935

Hylander, Clarence J. *The Sea and Shore.* The Macmillan Co., Chicago. 1950

Jaques, Harry E. *How to Know the Insects (2nd rev.).* Wm. C. Brown Co., Dubuque, Iowa. 1947

Kamm, Josephine. *Malaria Ross.* Criterion Books, Inc., New York. 1964

Lane, Frank W. *Kingdom of the Octopus: The Life of the Cephalopoda.* Sheridan House, Inc., New York. 1960

McCarthy, Agnes. *Creatures of the Deep.* Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 1964

Metcalf, C. L. and W. P. Flint. *Destructive and Useful Insects (4th Ed. Rev.).* McGraw-Hill Book Co., New York. 1962

Miner, Roy Waldo. *Field Book of Seashore Life.* G. P. Putnam's Sons, New York. 1950

Morgan, Ann Haven. *Field Book of Ponds and Streams.* G. P. Putnam's Sons, New York. 1930

Olsen, O. Wilford. *Animal Parasites: Their Biology and Life Cycles.* Burgess Publishing Co., Minneapolis, Minn. 1962

Swain, Ralph B. *The Insect Guide.* Doubleday and Co., Garden City, New York. 1948

Von Frisch, Karl. *Bees, Their Vision, Chemical Senses and Language.* Cornell University Press, Ithaca, New York. 1950

Walford, Lionel A. *Living Resources of the Sea.* The Ronald Press Co., New York. 1958

Articles

Singer, Marcus. "The Regeneration of Body Parts." Scientific American, October, 1958

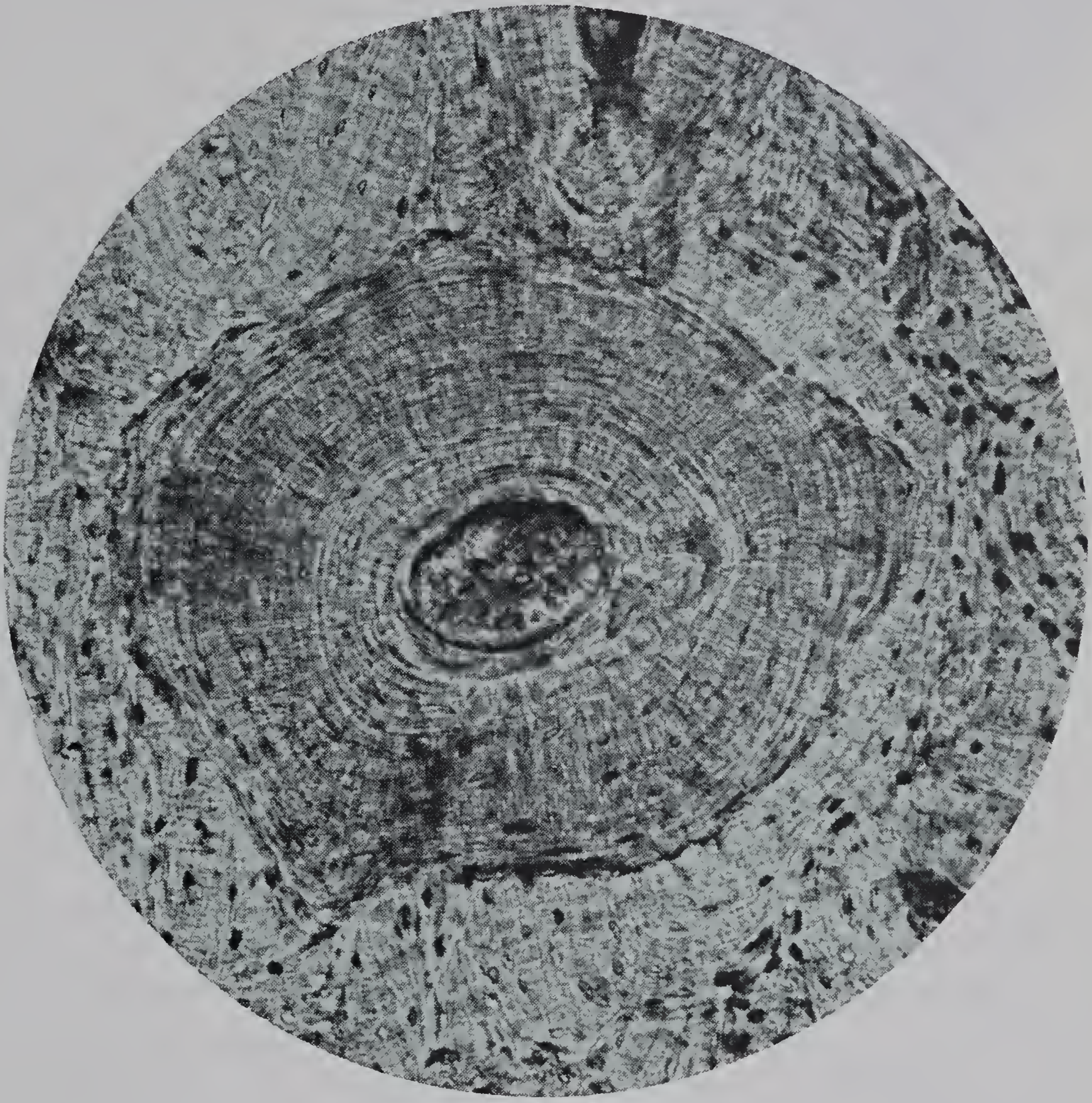
Waddington, C. H. "How Do Cells Differentiate?" Scientific American, September, 1953

Wenner, Adrian. "Sound Communications in Honeybees." Scientific American, April, 1964

Williams, Carroll M. "The Metamorphosis of Insects." Scientific American, April, 1950

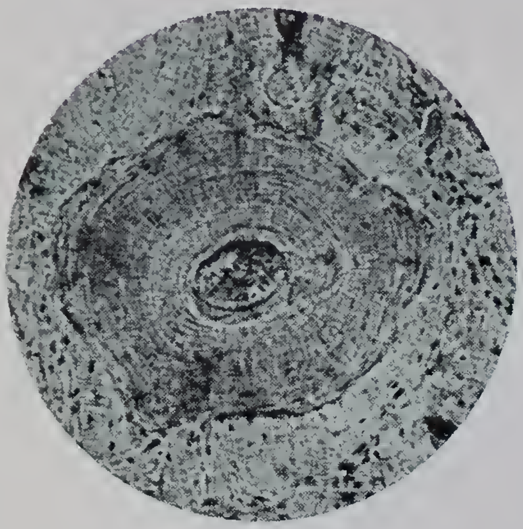
UNIT SIX

BIOLOGY OF THE VERTEBRATES



This unit introduces the most advanced of all animals — a group which surpasses others in structural organization and functional efficiency. The group is known as the vertebrates because its members have spinal columns composed of bones called vertebrae. The presence of a spinal column alone is not as important as the nerve cord it encases and the highly developed brain this nerve cord joins. A most efficient nervous system and the high-level responses and adjustments it permits are the key to the biological supremacy of the vertebrates.

CHAPTER 33



INTRODUCTION TO THE VERTEBRATES

A quick review of invertebrate development. Nature seems to have tried several plans of body development in various invertebrate animals. In the protozoans the specialization of a single cell is carried to the limit. Consider the paramecium with its cilia and trichocysts, its gullet and contractile vacuoles. The "slipper animalcule" is a truly marvelous cell, but it takes many cells to make a complex animal.

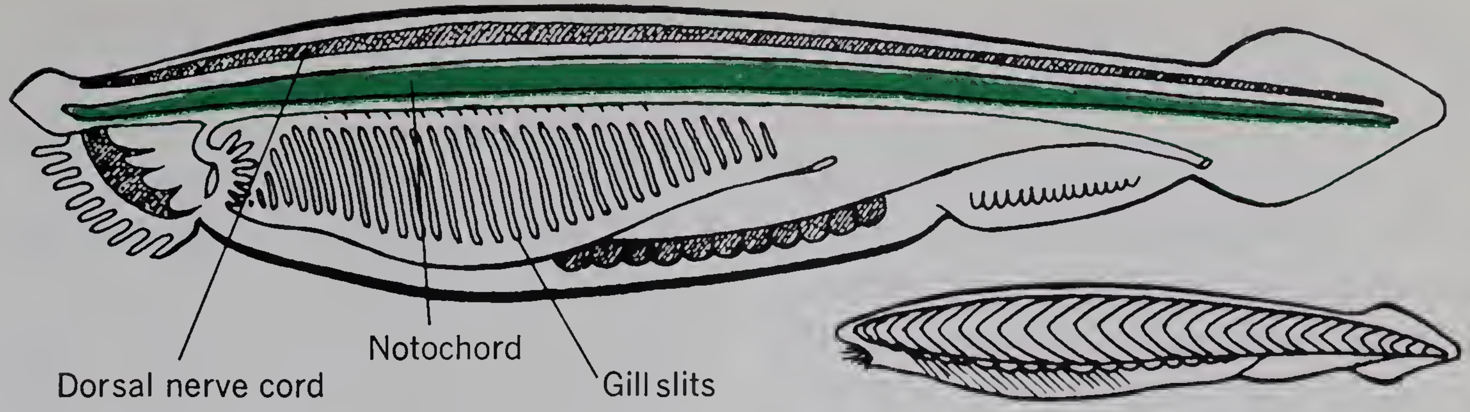
You were introduced to a large colony of cells in the sponges and coelenterates. The beginning of tissues is found in the ectoderm and endoderm of these animals. In the flatworms and roundworms there are organs that perform such functions as digestion, reproduction, excretion, and irritability with much greater efficiency. The segmented worms reveal a more advanced and efficient tubular digestive tract and an elongated body divided into a series of segments; a well developed circulatory system transports blood through closed vessels in this group of worms.

The clam and other mollusks have the greatest possible protection for a highly developed, soft-bodied animal. Their shells are both a fort and a prison. Mollusks, however, have not advanced much in many millions of years.

The arthropods combine protection with freedom of movement. But an exoskeleton capable of supporting a very large arthropod would be too heavy to move. Thus, arthropods have remained reasonably small. Numbers alone maintain their place of importance in the living world.

Why have the vertebrate animals become so important? The vertebrates include the fishes, amphibians, reptiles, birds, and mammals. They have neither shell nor hard exoskeleton (with the exception of certain reptiles and mammals). A strong internal framework, or endoskeleton, supports a body that is able to move freely and gracefully. Although this prevents protection of the soft body parts (except in certain vertebrates such as the turtle and armadillo, which have a hard outer covering), the highly developed vertebrate brain and nervous system more than make up for the lack of outer protection. In escaping from enemies, the vertebrate animals depend on their keen sense organs and efficient movement as well as on their instinct and intelligence.

Vertebrata – subphylum of the Chordata. The ***Vertebrata*** (ver-te-*bray*-tuh) is one of four subphyla of the phylum *Chordata* (kor-*day*-tuh). The other three primitive subphyla give us some



33-1 All chordates have a notochord in the early stages of their lives. Shown above is *Amphioxus,* a primitive chordate that retains the notochord throughout its life.

idea of the animals from which vertebrates probably evolved. One subphylum includes two classes of wormlike marine animals commonly called acorn worms. Another is represented by the strange tunicates, or sea squirts. The fishlike *Amphioxus* (am-fee-*ahk*-sus), probably the best known of the primitive chordates, represents the third subphylum. Only because of the vertebrates, however, is the phylum Chordata important today.

Early in life, all chordate animals have a gristlelike rod running lengthwise along the dorsal side of the body. We call this rod a ***notochord,*** from which the name of the phylum comes. The more primitive chordates keep their notochord throughout life. Some of the lower vertebrates, such as the sea lamprey, retain the notochord, but it becomes surrounded by cartilage structures of the spinal column. The notochord disappears early in the development of other vertebrates. It is replaced by the ***vertebrae*** of the spine, from which the name of the subphylum comes. Thus we usually speak of vertebrates as animals that have backbones.

Other characteristics of chordates include a nerve cord that runs down the dorsal side of the body. In vertebrates the bones of the spinal column enclose a dorsal nerve cord, or spinal cord. In invertebrates, such as the earthworm, the main nerve trunk lies on the ventral side of the body. The vertebrate nervous system is more complicated, larger, and more specialized than that of any other animal group.

All chordates have paired gill slits that form openings in the throat. Like the notochord, these disappear early in the development of the land vertebrates — the reptiles, birds, and mammals. Another characteristic of vertebrates is that they are able to produce antibodies in their blood as protection against infectious organisms.

The rise of the vertebrates. Since there is no direct fossil evidence of the ancestors of the vertebrates, biologists believe that they were soft-bodied lower chordates whose remains would have decomposed without leaving impressions in rocks. Fossil records hint that some lower chordates were passing through evolutionary changes some half billion years ago. Although biologists believe that backboned animals lived before the Ordovician period (Fig. 13–1, page 183), only a few fossils have been found in rocks of this period. Vertebrate fossils become more numerous in the rocks of the Silurian period. These aquatic forms had unpaired fins and no jaws, like the modern lamprey and hagfish, and a covering of tough, hard, bony plates.

Sharks and other fishes with skeletons of cartilage first appeared in the Devonian period. These were followed by fishes with bony skeletons. Both groups have survived to the present day. The first land vertebrates, the amphibians, appeared at the end of the Devonian period. The first reptiles appeared toward the close of the Carboniferous period. Mammals first appeared about the beginning of the Jurassic period, and the oldest bird fossils are found in rocks from the end of this time.

Fossil records show that many vertebrate forms appeared and disappeared. It has been estimated that not more than 1 percent of the amphibian, reptile, bird, and mammal species living in the Jurassic period have living descendants today. Paleontologists believe that there has been a tremendous turnover in the kinds of animals that have inhabited the earth. Evolution of the vertebrate animals will be discussed more fully as we consider each class in the following chapters. Living vertebrates are usually divided into seven classes, as shown in the Appendix. The classes are listed in order of their complexity.

Outstanding characteristics of vertebrates. Although fishes, frogs, reptiles, birds, and mammals may seem very different to you, they are actually similar in many ways. Their similarities include the following:

1. A body with a head and trunk and, in many, a neck and a tail.
2. Never more than two pairs of locomotive appendages present. These may be fins, flippers, wings, arms, or legs.
3. Eyes, ears, and nostrils in the head.
4. Eyelids and separate teeth present in most forms.
5. An internal skeleton (***endoskeleton***) of bone and/or ***cartilage*** (gristle).
6. A spinal column, or backbone, composed of vertebrae.
7. Two body cavities: a dorsal cavity for the nervous system; and a larger ventral cavity for the other internal organs.
8. A heart on the ventral side of the body; red blood corpuscles.

Specialized systems of the vertebrate body. The vertebrate systems contain many highly developed organs. These systems include the following:

1. *Integumentary system* — the outer body covering and special outgrowths such as scales, feathers, or hair for protection.
2. *Muscular system* — muscles attached to bones for body movement; muscles that form the walls of the heart and the digestive organs and blood vessels.
3. *Skeletal system* — the bones and cartilage that make up the body framework.
4. *Digestive system* — the many specialized organs concerned with the preparation of food for use by the body tissues.
5. *Respiratory system* — gills or lungs and related structures used in the exchange of gases between the organism and its external environment.
6. *Circulatory system* — the heart and blood vessels, which function as the transportation system of the body.
7. *Excretory system* — the organs that remove wastes from the body.
8. *Endocrine system* — glands that produce secretions necessary for the normal functioning of the other systems.

9. *Nervous system* — the brain, the spinal cord, nerves, and special sense organs — the most highly developed system of a vertebrate.
10. *Reproductive system* — the male or female organs of reproduction.

Lines of development in the vertebrates. The skeleton shows an interesting development in the vertebrate classes. The lampreys, sharks, and rays have a skeleton of cartilage throughout life. Fishes, amphibians, reptiles, birds, and mammals develop a bony skeleton. These animals start life with a cartilaginous framework. But early in life bone cells replace most of the cartilage. Minerals deposited in the bones make them hard and strong.

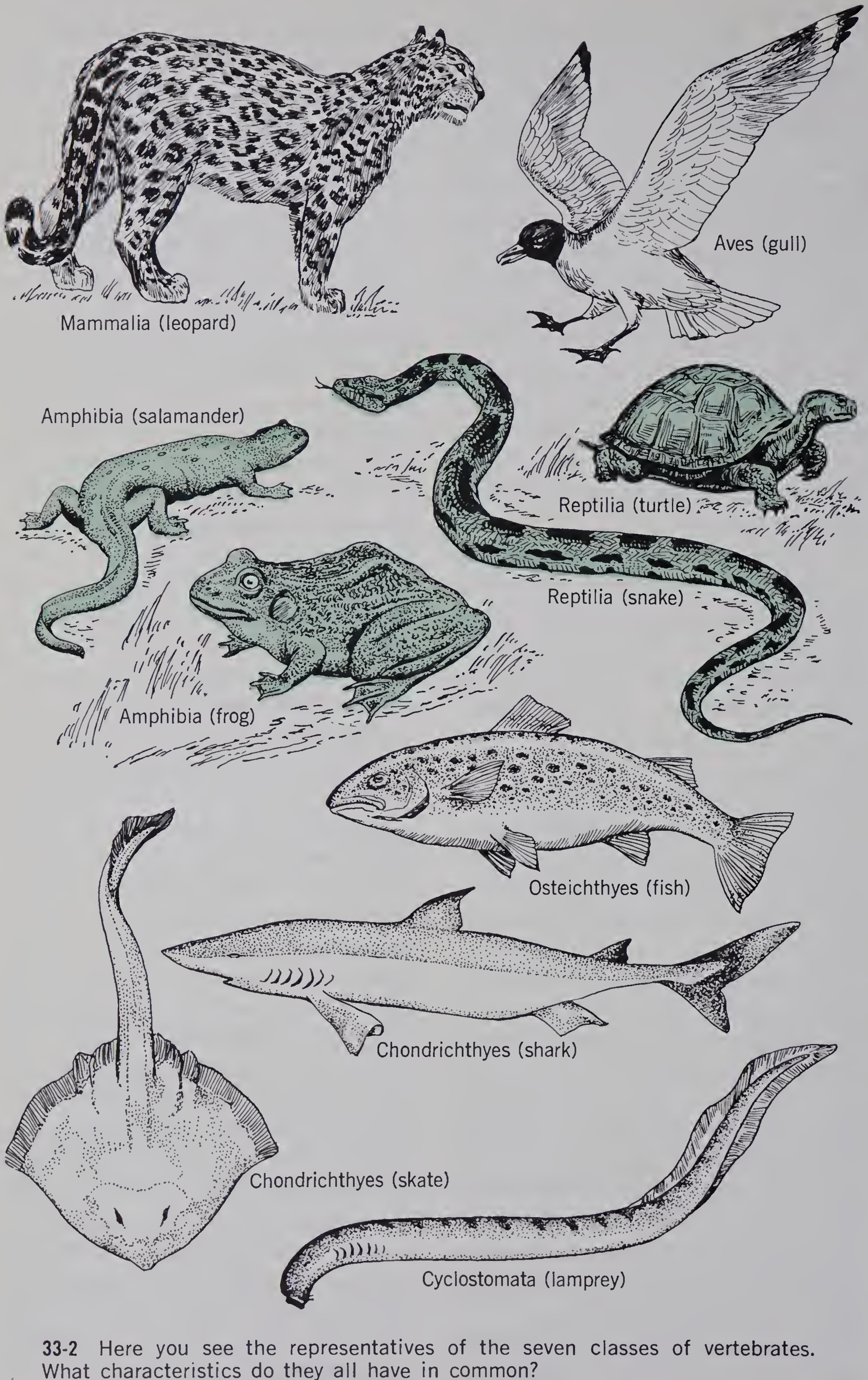
The classes of vertebrates also show an interesting change from water existence to life on land. The lampreys, sharks, rays, and bony fishes are adapted only for life in water. Their limbs are in the form of fins. Their gills absorb dissolved oxygen from the water. Water flows over the gills through gill slits in the throat. After you have studied the frog as a representative amphibian, you will realize that it represents a transition from water to land. During the tadpole stage, a frog is a fishlike animal with gills and a fin.

The vertebrate heart and brain show great development over those of the invertebrates. The fish heart has only two chambers. One chamber receives blood from the body, while the other pumps blood to the gills. The frog has a three-chambered heart and a more complex circulatory system. Birds and mammals have still more complex hearts consisting of four chambers. One side of the heart receives blood from the body and pumps it to the lungs. The other side receives blood from the lungs and pumps it to the body. This heart is really a double pump. Man's heart likewise consists of four chambers.

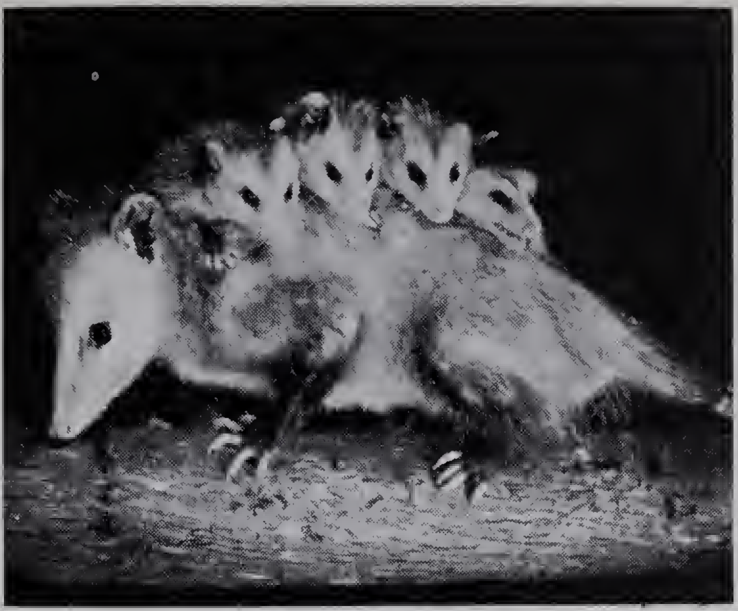
Similar advances can be seen in the brain of the vertebrates. One brain region, known as the ***cerebrum,*** is the center of instinct, emotion, memory, and intelligence. This brain area increases in relative size through the classes of vertebrates. The brain of the mammal has the largest cerebrum in relation to the size of the body.

The highly developed behavior of vertebrates. Behavior is the way in which an organism responds to stimuli. The type of sense organs, nerve pathways, and organs specialized for nervous control determine the stimuli to which organisms are sensitive and in many respects the responses they can make. Protists and plants have no specialized nerve tissue. Their responses are limited to simple tropisms. The nerve net of the hydra enables it to behave as a unit. The sense organs, nerve cords, and ganglia of the higher invertebrates permit even more integrated behavior. In the vertebrates, the highly developed sense organs, brain, and nerves extending to and from all parts of the body provide the basis for complex behavior.

Much of the activity of a higher animal is inborn, or ***innate behavior.*** Since such behavior is inherited, it is reasonable to assume that it is controlled by genes. ***Reflexes*** are simple innate responses. In a reflex, an animal automatically responds in a certain manner to a given stimulus. For example, stimulation of the surface of the eye or eyelid will cause blinking. Reflexes are involuntary; that is, the animal reacts to the stimulus without any control on its part. Generally reflexes protect the organism from harm. Even man depends on reflex behavior for many of his responses.


Mammalia (leopard)
Aves (gull)
Amphibia (salamander)
Reptilia (turtle)
Reptilia (snake)
Amphibia (frog)
Osteichthyes (fish)
Chondrichthyes (shark)
Chondrichthyes (skate)
Cyclostomata (lamprey)

33-2 Here you see the representatives of the seven classes of vertebrates. What characteristics do they all have in common?



33-3 Species preservation is one of the strongest instincts in animals. These opossum babies ride safely on their mother's back until they are able to take care of themselves. (Encyclopaedia Britannica Films)

The most interesting and the least understood of the innate responses are those that we call ***instincts.*** Instincts are complex patterns of unlearned behavior. They are involuntary, since the animal performs them without a deliberate decision.

Self-preservation is a basic instinct in all vertebrates as well as in many invertebrates. In times of danger an animal will respond to the "flight or fight" instinct of self-preservation. Have you ever cornered an animal that would normally flee? A seemingly harmless animal like a squirrel will bite and claw viciously if it cannot escape from an enemy. The suckling instinct, another example of self-preservation, directs the nursing mammal early in life. The self-preservation instinct causes the tiny bird to pick its way through the shell at the time of hatching.

A second instinct, that of ***species preservation,*** directs animal reproduction and care of the young. This is the instinct that, for instance, drives the Pacific salmon up the streams of the Northwest to spawning beds. The adult salmon lose their lives and a new generation comes downstream to the ocean. This instinct also causes the sunfish to defend its nest against an intruder from which it would normally flee.

Biologists have found that instinctive behavior is important to animals with a short life span, such as the insects. Some insects have only a few days or even a few hours in which to reproduce their kind. If they had to take the time to learn how to survive, they would probably become extinct.

Because of their well developed nervous systems, vertebrates are capable of learned behavior as well as innate behavior. A ***conditioned reaction*** is a form of learned behavior common among vertebrates. We say that a reaction becomes conditioned when a particular behavior response continually follows a specific stimulus, resulting in habit formation. We develop this level of behavior when we teach a dog to heel at a command or shake hands at a given signal. Even fishes in an aquarium can be trained to go to one special corner of the tank when you approach, if you always feed them in this particular place.

Intelligent behavior is still more complicated. An intelligent response is a deliberate act that involves memory of past experiences, association, and judgment. Instinct can be observed in all vertebrates. To a lesser degree most of the vertebrates are capable of conditioned reactions. Birds and mammals exhibit intelligent behavior to some degree. Man, however, is supreme among the vertebrates in development of intelligence. He is also unique among living things in his ability to learn to communicate by symbols, both in speaking and in writing.

IN CONCLUSION

As you study the vertebrates, you will see some characteristics developed to the highest degree. The fish excels in swimming — its streamlined body cuts through the water like a torpedo. The frog is at home both on land and in the water. The bird has long been the model for life in the air.

The antelope and gazelle hold speed records among land animals. The elephant is a symbol of strength. What about man? Man is no match for other vertebrates in physical abilities, but his is the superior brain.

In the next chapter, we shall begin our study of vertebrates of the ocean depths, lakes, rivers, and streams. Here the primitive fishlike vertebrates and the many bony fishes, the most important of aquatic animals, are found.

BIOLOGICALLY SPEAKING

cartilage
cerebrum
Chordata
conditioned reaction
endoskeleton
innate behavior
instinct
intelligent behavior
notochord
reflexes
self-preservation
species preservation
vertebrae
Vertebrata

QUESTIONS FOR REVIEW

1. Distinguish the vertebrate skeleton from that of lower animals?
2. Name seven classes of vertebrates and give an example of each class.
3. Which is more efficient, the endoskeleton or the exoskeleton? Why?
4. Describe and locate the notochord.
5. How would you distinguish the vertebrates from the other chordates?
6. What are eight vertebrate characteristics?
7. Name ten vertebrate systems.
8. Which of the various brain regions is the center of instinct, emotions, and intelligence?
9. What is the relation between a stimulus and a response?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the development of vertebrates through the various classes, using the skeleton, organs of respiration, heart, and brain as illustrations.
2. Self-preservation and species preservation are instincts. Which is stronger? Give one or more illustrations to prove your answer.
3. How can you distinguish instinctive behavior from intelligent behavior in observing the activity of various vertebrate animals?
4. Why are instinct and intelligence more vital to survival of a vertebrate than to an invertebrate such as a clam, a starfish, an insect, or a crayfish?

CHAPTER 34

THE FISHES

Blood-sucking "vampires" of the Great Lakes. About 40 years ago a deadly vertebrate menace made its way from the waters of Lake Ontario through the Welland Canal at Niagara Falls and into Lake Erie. The sea lampreys were invading new waters. During a much earlier period this species had become established in Lake Ontario. Here their movement was stopped by Niagara Falls. But the Welland Canal, built to carry shipping around the falls, gave them passage into Lake Erie. Ten years later the lamprey hordes had spread through Lake Huron. They traveled through the Straits of Mackinac into Lake Michigan and through the locks at Sault Sainte Marie into Lake Superior.

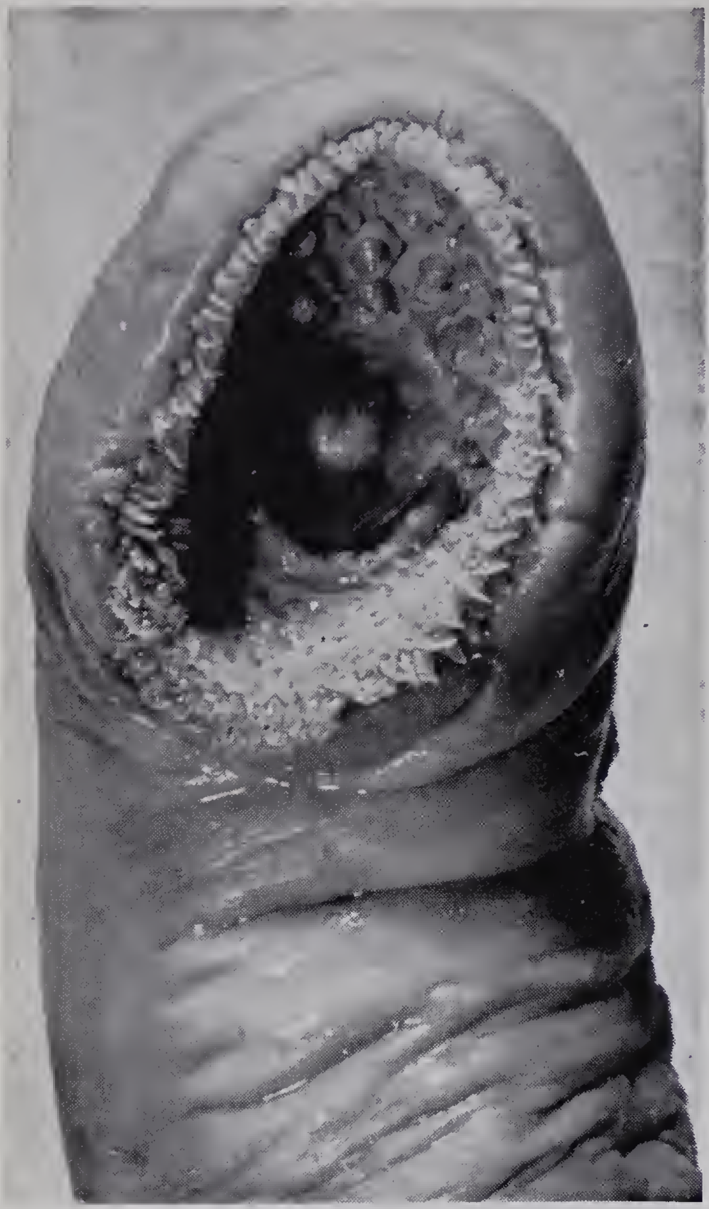
What sort of creature is this death-dealing sea lamprey? Biologists place it in the class ***Cyclostomata*** (sy-klos-toh-*may*-tuh), which means "round-mouthed." This small class of primitive vertebrates is also sometimes called *Agnatha* (ag-*nay*-tha), which means "jawless." Ancestors of the cyclostomes are believed to have been the first vertebrates, appearing in the Ordovician period (Fig. 13–1, page 183).

The sea lamprey has a slender eel-like body. The mature lamprey reaches a length of about two feet and a weight of about one pound. Its skin is soft and slimy, brownish-green, and blotched or mottled. Paired fins are lacking in the lamprey. Two single fins along the back and a tail fin aid the lamprey in swimming in its characteristic rippling manner.

The head of a lamprey is curious and quite different from that of a fish. Instead of jaws the lamprey has a funnel-like mouth lined with sharp, horny teeth (Fig. 34–1). A rasping tongue, also bearing teeth, lies in the center of the mouth. Small eyes are situated on either side of the head. Between the eyes, on the top of the head, is a nasal opening that leads to a sac containing nerve endings associated with the sense of smell. Seven oval gill slits, resembling portholes of a ship, lie in a row on each side of the head behind the eyes.

During its adult life the sea lamprey is a very destructive predator. It attaches its sucking mouth to the side of a fish and gouges a hole through the scales with its rasping teeth (Fig. 34–2). It feeds on the blood and body fluids of its victim and may even suck out internal organs. When it has killed or weakened a host fish, the lamprey moves on to another. The injury is not always fatal, for many healthy fishes with lamprey scars are found. Its favorite host is the lake trout, one of the most important commercial fishes of the Great Lakes. When trout are not available, the sea lamprey attacks whitefish, pike, and other species.

The sea lamprey has exterminated the lake trout in Lake Huron and Lake

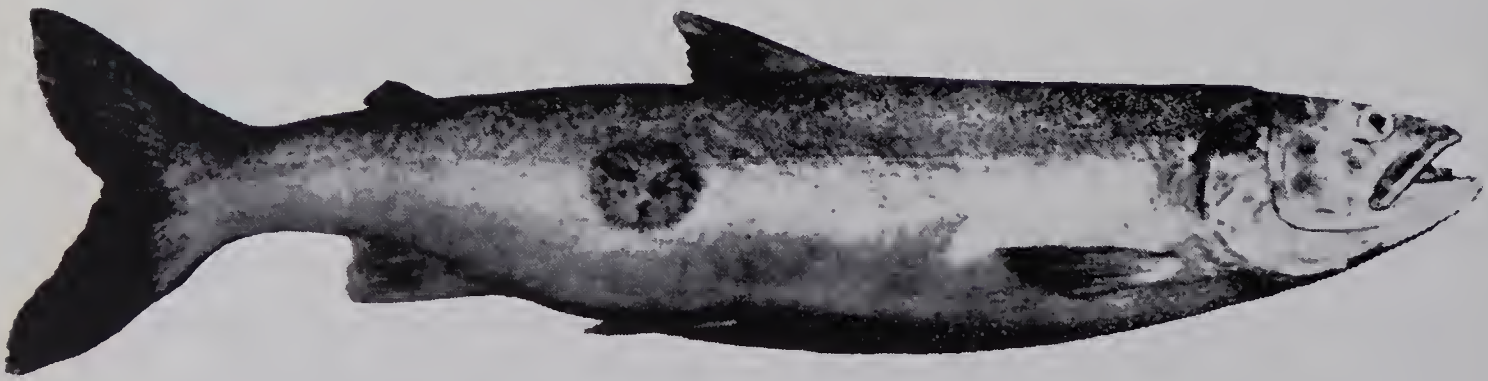


34-1 This close-up view of the sucking mouth of a sea lamprey shows how it can attach itself to the body of a fish and feed on the blood and body fluids of its host. (U.S. Fish and Wildlife Service)

Michigan and has seriously reduced the population in Lake Superior.

Our hope of eliminating the lamprey menace. The spawning habits of the lamprey are helping us to destroy this deadly menace. Sea lampreys reach sexual maturity in the Great Lakes during the months of May or June. At this time they enter fast-flowing streams that feed the lakes. They lay their eggs in circular depressions in the gravel bottom of cold streams. An average female lays from 50,000 to 100,000 eggs. After about 20 days of development, the eggs hatch into tiny, blind larvae. The larvae leave the nest and float downstream until they reach quiet water with a mud bottom. Here they burrow into the mud and start a period of inactive life. During this period the larva lies in a U-shaped burrow and feeds on plant and animal matter drawn into the mouth in a current produced by moving cilia. After five or more years in the stream, the larva changes to an adult and starts its journey downstream to the lake. It lives about one year as an adult, feeding constantly on fish.

Two methods of lamprey control have been used. One frequently used is the lamprey trap, designed to capture the adults as they migrate upstream to spawn. Electrodes charged with electricity are put in a row across the stream; this charges the water and stops the movement of all kinds of aquatic animals. The migrating lampreys and fishes swim along the edge of the charged area into traps. Here the lam-



34-2 This trout bears the scar left by a sea lamprey. (U.S. Fish and Wildlife Service)

34-3 The shark has strong and sharp teeth which can inflict fatal wounds to its prey. (Annan Photo Features)

preys are destroyed. The fishes are caught and put back into the stream above the traps.

A more recent method of lamprey control that has replaced many electric barriers makes use of a selective poison which kills the larvae buried in the streams. It has been used extensively in Lake Superior, where it has reduced the lamprey population about 80 percent, and is now being applied in Lake Michigan.

Sharks and rays. To the class *Chondrichthyes* (kon-*drik*-thih-eez), which means "cartilage fishes," belong the few remaining fishes of those that controlled the ancient seas. Sharks, rays, and skates make up this class of fishes, which is also called *Elasmobranchii* (i-laz-moh-*brank*-ee-ee), meaning "plated gills." The shark resembles the true fishes in many ways, but certain characteristics put it in a separate class.

The body of a shark is torpedo-shaped. Its fins resemble those of true fishes. The upper portion of the tail fin is longer than the lower portion — a characteristic of ancient fishes. The shark's mouth is a horizontal slitlike opening on the ventral side of the head. The jaws of most species are lined with sharp razor-edged teeth. Water enters the mouth, passes over the gills on each side of the head, and is forced out through pairs of gill slits. Gills, as you probably know, are the special respiratory organs of fishes and their relatives. As the name of the class implies, the skeleton of sharks and rays is composed of cartilage rather than bone.

Sharks include the largest living fishes. The whale shark, the giant of sharks, reaches a length of 50 feet or more and a weight of over 20 tons. The great white shark, or man-eating shark, may exceed 40 feet in length.

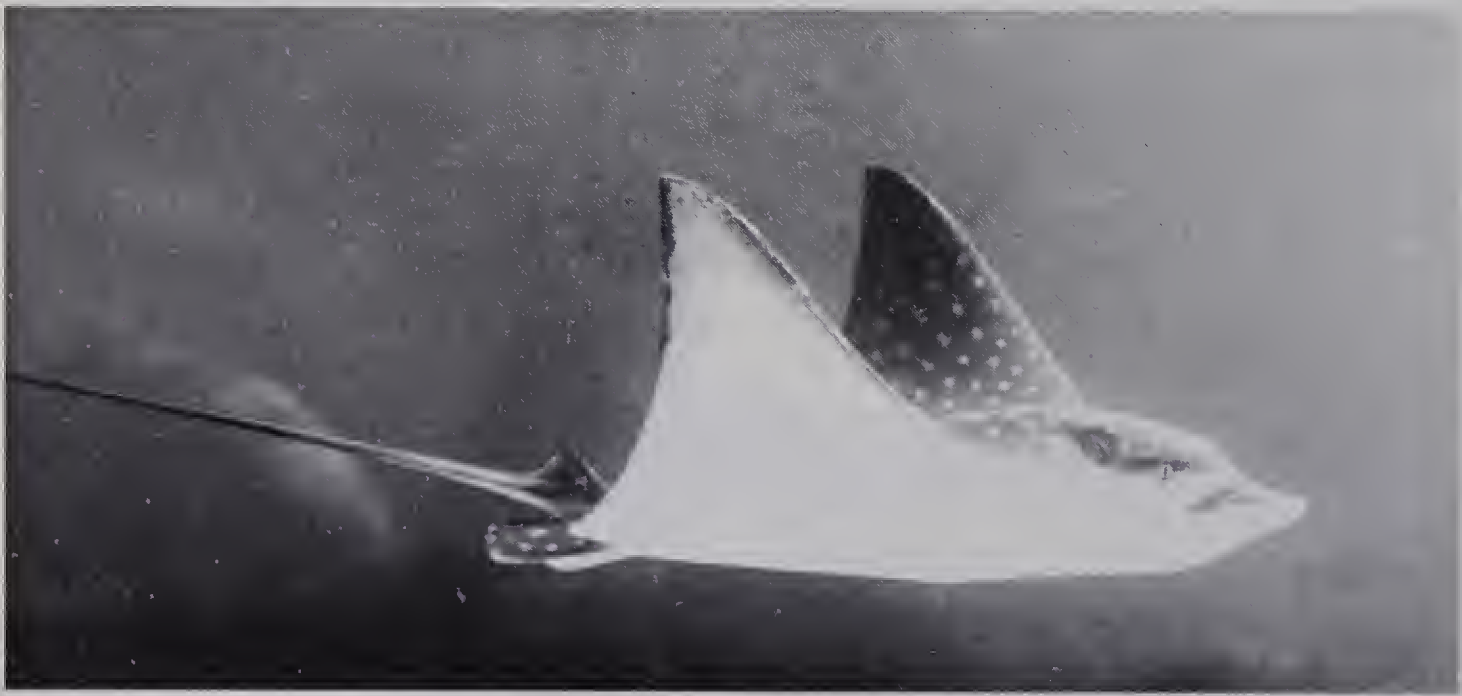
Reports of attacks by sharks have increased as more people turn to the water for recreation. Scientists are beginning to ask how the shark locates its prey. Does it depend on sight, smell, or both? When opaque plastic eye shields are put over a shark's eyes, the "blinded" shark takes longer to find food. Thus sight must be important in locating prey. It has been demonstrated that sharks can smell blood for only a few hundred feet, but that they can detect sound over some distance. It may be that they are first attracted to possible victims by the sound of splashing water.

The rays and skates have broad, flat bodies, with whiplike tails. Rays swim gracefully through ocean waters, moving their flat bodies like wings. They often lie half buried in the sand of the ocean bottom. The tail has a sharp barbed spike near the tip that causes a painful wound when driven into a victim. Sting rays often come close to shore. The torpedo ray has an excellent means of defense. It is equipped with electric organs so powerful that they can knock a man off his feet. This adaptation is probably used for obtaining food.

The skate has a triangular-shaped body with a long, thin tail. Locomotion is by the triangular pectoral fins, which undulate from front to rear, rather than flapping like wings. Two fins attached to the rigid tail act as a steering device.

Skates are well adapted for life on the bottom of the ocean. Water is taken in through two spiracles located on top of the head, just back of the eyes. Then the water passes out through the gill slits underneath. Thus skates avoid taking in debris when they respire.

The true fishes. Biologists put all the true fishes in the class ***Osteichthyes*** (os-tee-*ik*-thih-eez), which means "bony fishes." Their bony skeleton distinguishes them from the lampreys, sharks, and rays of modern times. This class is sometimes called *Teleostomi* (tel-ee-*os*-toh-mee), which means "complete-mouthed," to distinguish its members from the cyclostomes. The bony fishes first appeared in the Devonian period, which is often called the age of fishes



34-4 The sting ray is found in warm waters and has a long whiplike tail provided with a barbed stinger capable of inflicting a severe wound. (Annan Photo Features) because Devonian rocks contain the greatest numbers and variety of fish fossils. This was a time of rapid evolution for the fishes because their members were so widely distributed then.

Bony fishes have ***gills*** as respiratory organs. Limbs are in the form of ***fins.*** Most fishes have an outer covering of overlapping ***scales,*** or plates. Fishes are ideally suited to aquatic life. In a wide variety of forms they live in practically every water environment of the earth.

The body of a fish is divided into three regions: head, trunk, and tail. In most species the body is perfectly streamlined — tapered at both ends, or spindle-shaped. The lack of a neck is no disadvantage to a fish. It can turn its body as easily in the water as most other animals can move their heads.

Many people confuse the tail of a fish with the tail fin. The tail is the solid muscular region posterior to the trunk. The tail fin is an outgrowth of this region.

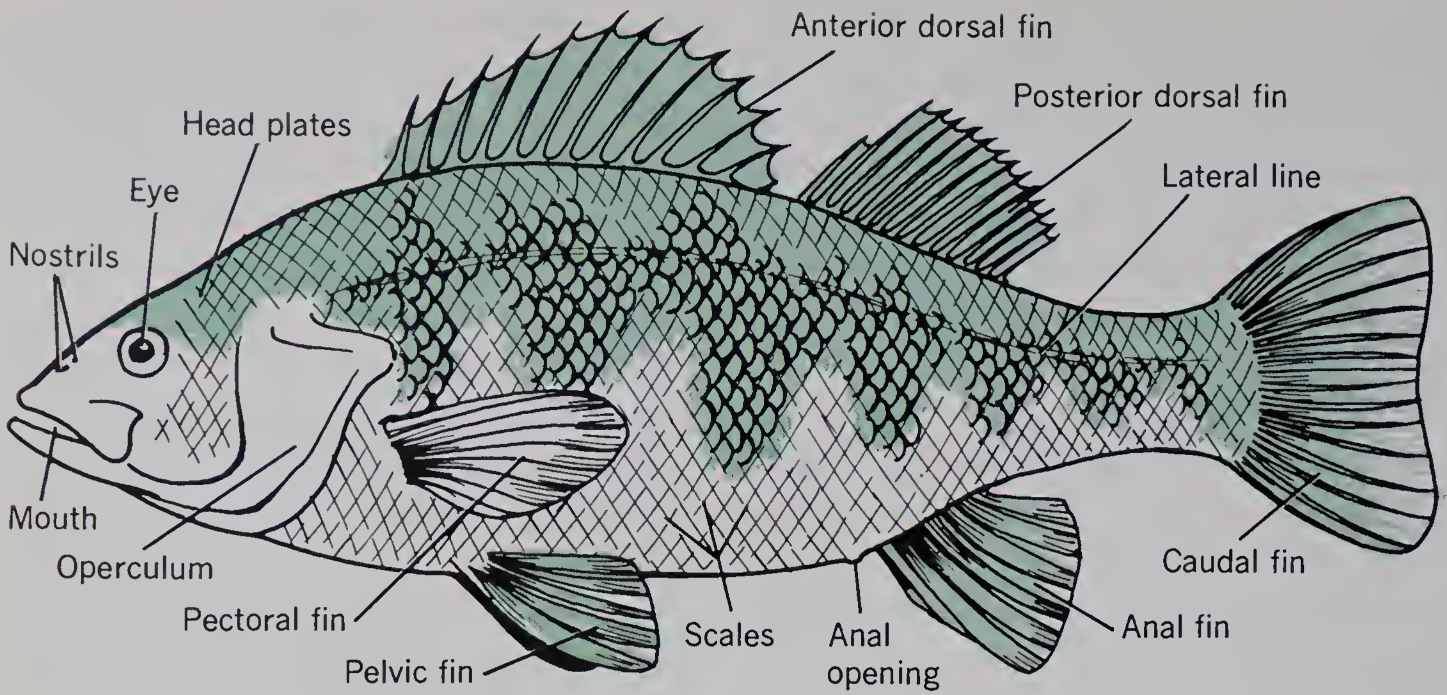
The body covering of fishes. Scales grow from pockets in the skin and overlap like shingles on a roof. Scales increase in size as a fish grows. In other words a young fish has the same number of scales it will have at maturity. As scales grow, concentric rings are formed. These rings are closer together in regions of winter growth than in summer growth, thus making it possible to distinguish seasons of scale growth and determine the age of the fish.

A slimy secretion of the skin seeps between the scales and forms a covering that lubricates the body. This body slime is important in locomotion and in escape from enemies. It is important, too, in protecting the fish from attack by parasitic fungi, bacteria, protozoans, and other organisms. If you handle a fish with dry hands, you remove some of the slime and expose the body to parasites. You can avoid this by wetting your hands before you pick up a fish.

Many fishes have bright colors, often arranged in lines, bars, or spots. Much of the coloration of fishes is due to pigment granules present in special cells of the skin known as ***chromatophores*** (kroh-*mat*-uh-fohrz). Color may also be caused by ***guanin*** (*gwah*-nin) ***crystals,*** which are excretory products found in the scales, skin, eye, and air bladder. The chromatophores are supplied with nerves, but there is no nerve supply to the guanin crystals.

Many fishes have a remarkable ability to alter their colors in a short time, as a means of camouflage. Light stimuli received by the eye are transmitted to the brain. Then nerve impulses are sent to the chromatophores, causing the pigment granules either to spread out or clump together. Bright or dark colors appear when the pigments spread out. The colors fade when the pigments clump together. Colors produced by granules in the chromatophores show through the transparent scales. Other colors of fishes are due to the reflection of light from the scale surfaces and interference of the guanin crystals.

Many fishes illustrate ***countershading,*** another means of camouflage. Darker pigments on the dorsal side of the body tone down the bright light that strikes the fish from above. As a result the upper side blends with the lighter side, giving the body a uniform appearance when viewed from the side. The darker colors on the dorsal side blend with the bottom or with deep water when the fish is seen from above. The light colors on the ventral side blend with the bright light on the surface when the fish is viewed from below.



34-5 This drawing shows the external structure of a bony fish, the yellow perch.

Head structures of the fish. Although different species of fish vary greatly in body form, many fishes are similar to the yellow perch, shown in Fig. 34–5. The head tapers toward the mouth, offering the least possible resistance as the fish moves through the water. The protective covering of the head is in the form of plates instead of scales. The mouth is large and is situated at the extreme anterior end. Carnivorous fishes such as the yellow perch have numerous small, sharp teeth extending from the jawbones and from the roof of the mouth. These teeth slant toward the throat, making it easy for the yellow perch to swallow a prey, but hard for the prey to escape. The tongue is fastened to the floor of the mouth and is not movable. It functions as an organ of touch rather than one of taste.

Two nasal cavities lie on the top of the head, anterior to the eyes. Paired nostrils lead to each nasal cavity. The nostrils function in smell only. They do not connect with the throat and are not involved in respiration. The fish has no external openings to the ears. The ears are embedded in the bones of the skull and probably function as balance organs in addition to receiving vibrations carried by the bones of the skull.

The eyes of most fishes are large and somewhat movable. Eyelids are lacking. The pupils are large compared with those of other vertebrates, and admit the greatest possible amount of light.

At each side of the head is a crescent-shaped slit that marks the posterior edge of the gill cover, or ***operculum*** (oh-*per*-kyoo-lum). This hard plate serves as a protective cover for the gills beneath it. By raising the unattached rear edge of the operculum, you can see the gills lying in a large gill chamber. The edges of the opercula nearly meet on the lower side of the fish, where the head fastens to the trunk at a narrow ***isthmus.***

Structures of the trunk and tail. Various kinds of fins develop from the trunk and tail. Each fin consists of a double membrane supported by cartilaginous or spiny rays. Fins serve a variety of purposes in the fish and differ in form in various species.

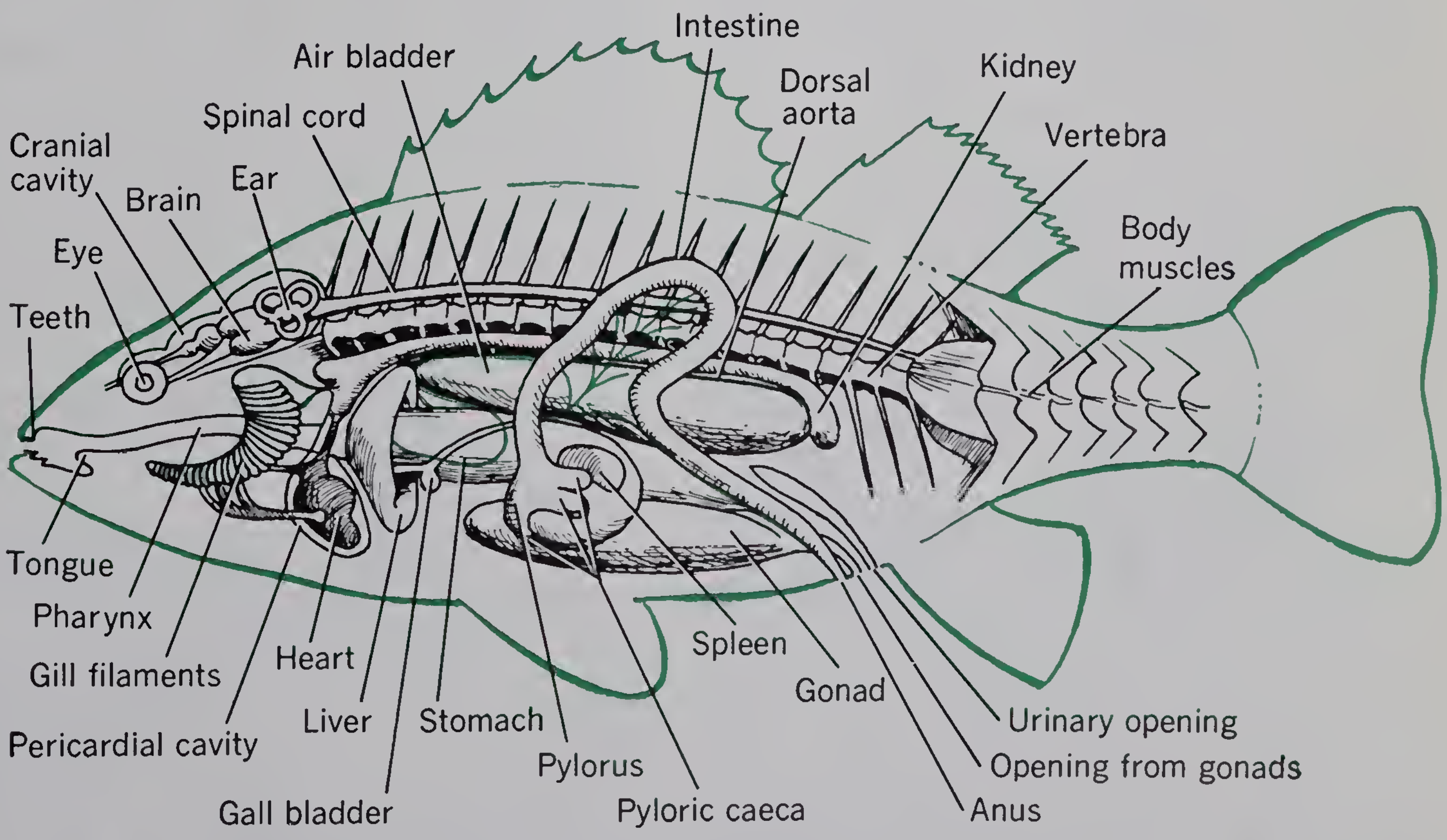
Two kinds of fins are paired. These are considered homologous with the limbs of other vertebrates. The ***pectoral fins*** are nearest the head, and correspond to the front legs of other vertebrates. Posterior to these are the ***pelvic fins,*** which correspond to hind legs. The paired fins serve as oars when the fish is swimming slowly. They also aid in steering and in maintaining balance when the fish is resting, and are used in moving backward. The ***caudal fin*** grows from the tail and aids in propelling the fish.

Dorsal fins are situated along the top middle line of the trunk. The anterior, or spiny, dorsal fin of the perch contains sharp projections that aid in defense. The spines of this fin raise upward toward the head, thus making it difficult to swallow the perch tailfirst. The posterior, or soft, dorsal fin lacks these spines. Both dorsal fins serve as a keel to keep the fish upright while swimming. Another single fin, the ***anal fin,*** grows along the middle line on the lower side. This fin, like the dorsal fin, serves as a keel and helps to maintain balance.

Powerful muscles, arranged in zigzag plates, occupy the region of the trunk above the spinal column. A thinner muscle layer lies along the body wall on the sides of the trunk. The tail region is solid muscle with the spine running through most of it.

If you examine the sides of a fish closely, you will notice a row of pitted scales extending from the head to the tail fin. These make up the ***lateral line.*** Nerve endings and a narrow tube lie under the scales. The line acts as a sense organ as it is sensitive to low frequency underwater vibrations.

The digestive system of the fish. Many fishes are vegetarians and feed on algae and other water plants. Carnivorous species eat other animals such as frogs, other fish, and a wide variety of invertebrates, including crayfish, worms, and

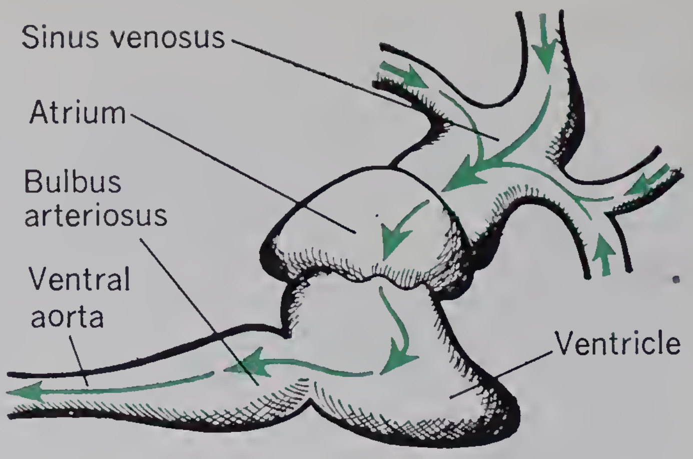

Intestine
Air bladder
Dorsal aorta
Kidney
Spinal cord
Vertebra
Cranial cavity
Ear
Brain
Body muscles
Eye
Teeth
Tongue
Pharynx
Gill filaments
Heart
Spleen
Gonad
Pericardial cavity
Liver
Stomach
Urinary opening
Pylorus
Opening from gonads
Gall bladder
Pyloric caeca
Anus

34-6 This is a lateral view of a dissected yellow perch.

insects. Some fishes, like the bass and pike, swallow fish almost as large as themselves. Especially in carnivorous fishes, the mouth is a large trap for capturing prey. The throat cavity, or ***pharynx***, leads to the opening of the short ***esophagus*** (Fig. 34–6). The esophagus in turn joins the upper end of the stomach. The ***stomach*** is in line with the esophagus, thus allowing a large prey to extend from the stomach through the mouth and even protrude for a time as digestion occurs. A rather short ***intestine*** leads from the lower end of the stomach. Several short tubes called the ***pyloric caeca*** (py-*lor*-ik *see*-ka) extend from the intestine and secrete digestive fluids. Digestion continues as food moves through the short loops of intestine. A well developed ***liver*** lies close to the stomach. Digested food is absorbed through the intestine wall. Indigestible matter leaves the intestine through the ***anus*** on the lower side.

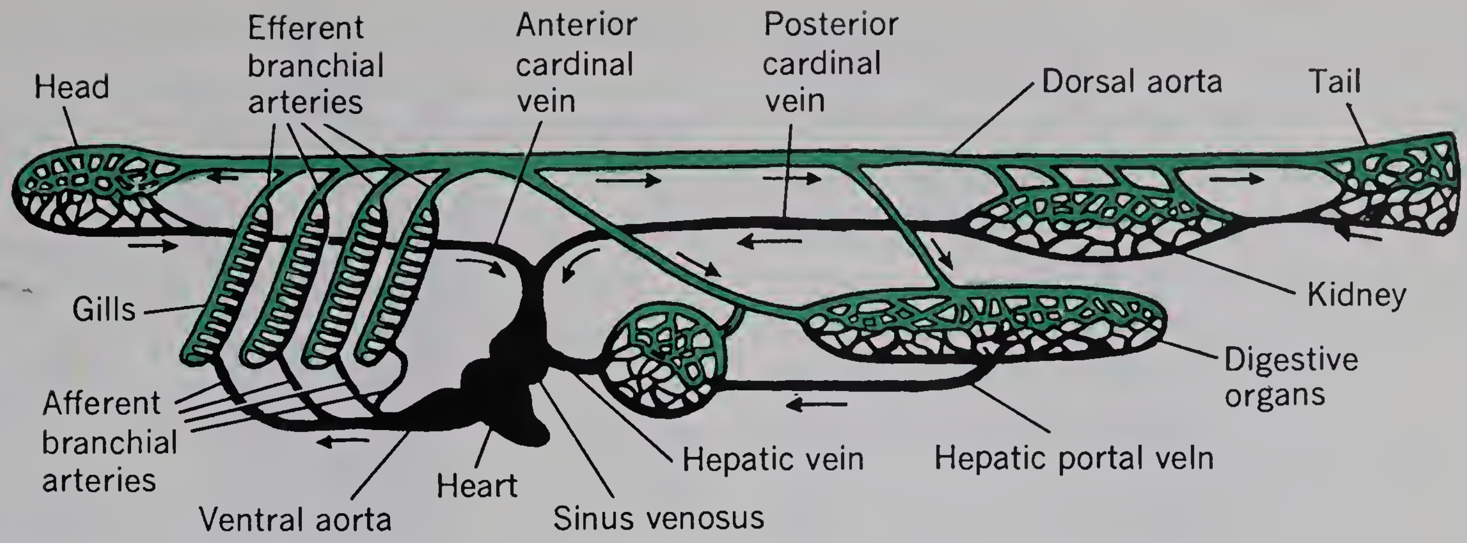
Circulatory system of a fish. The blood of a fish is similar to that of other vertebrates. It contains both red and white corpuscles. The ***heart*** (Fig. 34–7) pumps blood through a system of vessels of three types. ***Arteries*** carry blood from the heart to the gills, then to all other regions of the body. The arteries lead to thin-walled ***capillaries***, which penetrate all of the body tissues. The capillaries come together to form larger vessels called ***veins***, which return blood to the heart.

The heart lies in the ***pericardial cavity*** on the lower side of the body just behind the gills. A large vein, the ***cardinal vein***, receives blood from various branches coming from the head, trunk and tail, and the liver (Fig. 34–8). Just above the heart the cardinal vein enlarges into a thin-walled sac, the ***sinus venosus***. This sac joins the first heart chamber, or ***atrium***, often referred to as the *auricle*. From the atrium blood passes into the ***ventricle***, the thick-walled, muscular pumping chamber of the heart. Blood is pumped from the ventricle with great force through the ***ventral aorta***, leading to the gills. This artery begins with a muscular bulblike structure, the ***bulbus arteriosus***, which is attached to the ventricle. This structure is very noticeable in the fish heart. The ventral aorta branches to the two sets of gills, then rebranches to form arteries that lead to the four gills on each side of the head. Another large artery, the ***dorsal aorta***, receives blood from the gills and, through its branches, supplies the head, trunk, and tail. Blood returns to the heart through the cardinal veins, thus completing the circulation. Some of the blood returns through veins from the digestive organs and the liver. Various cell wastes are removed as blood circulates through the kidneys.



34-7 The fish heart has only one atrium and one ventricle.

The blood of a fish passes through the heart once during a complete circulation. The heart receives deoxygenated blood from the body tissues through the cardinal vein and pumps it through the ventral aorta to the gills. In circulating through the gills, the blood discharges carbon dioxide and

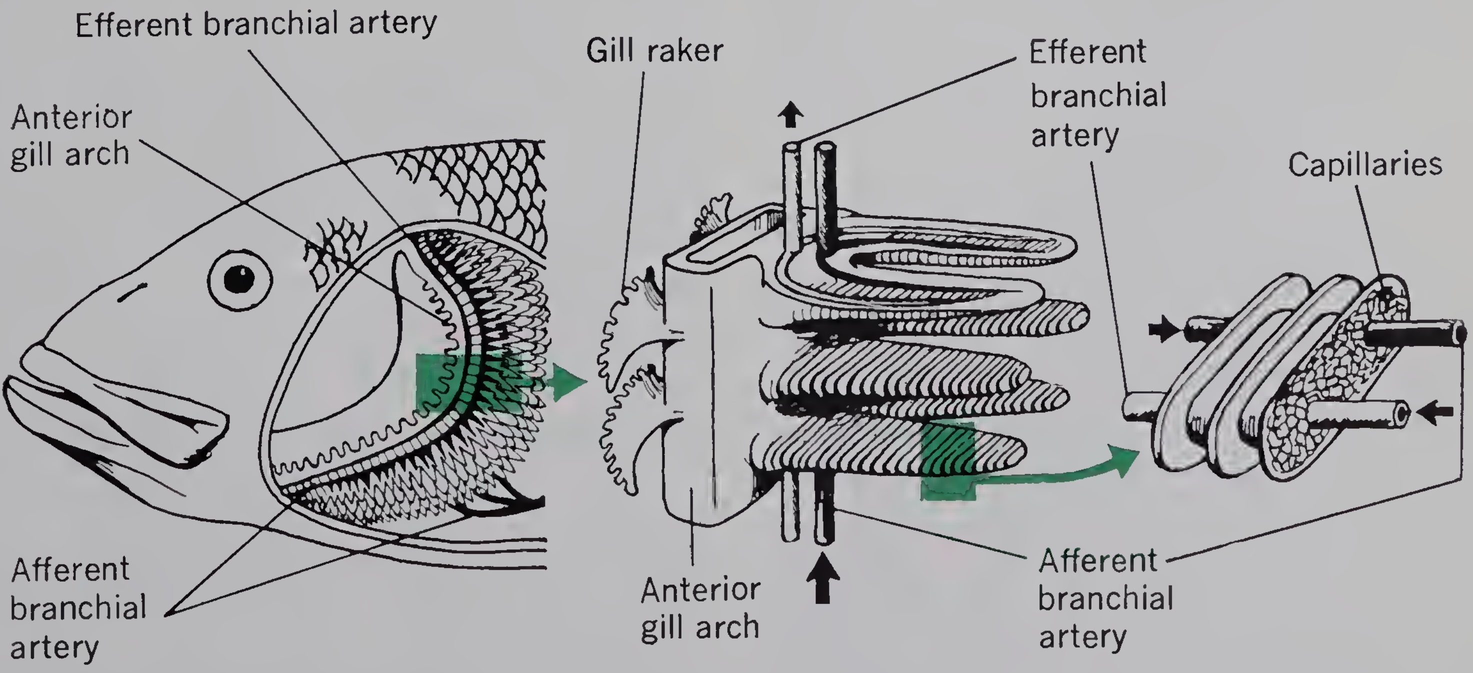

Head
Efferent branchial arteries
Anterior cardinal vein
Posterior cardinal vein
Dorsal aorta
Tail
Kidney
Gills
Digestive organs
Afferent branchial arteries
Hepatic vein
Hepatic portal vein
Heart
Ventral aorta
Sinus venosus

34-8 In this diagram, which shows circulation in the fish, note that the blood flows in a single circuit: from the body to the heart, to the gills, and to the body again.

receives oxygen. This blood, now oxygenated, is received from the gills by the dorsal aorta for circulation to the body tissues.

The gills — organs of respiration. In a bony fish such as the yellow perch, four gills lie in a gill chamber on each side of the head. A gill consists of a cartilaginous ***arch*** to which is attached a double row of thin-walled, threadlike projections called ***gill filaments*** (Fig. 34–9). These filaments are richly provided with capillaries, so that the blood is brought into close contact with the water over a large surface. The gill arches have hard, fingerlike projections called ***gill rakers*** on the side toward the throat. These prevent food and other particles from reaching the filaments and keep the arches apart to allow free circulation of water.

Blood enters a gill at the base of the arch through the ***afferent branchial artery*** (*af*-fur-ent *bran*-kee-al *ar*-tur-rhee). Branches of this artery enter each gill filament, where the blood enters a network of capillaries. Here carbon dioxide is discharged from the


Efferent branchial artery
Anterior gill arch
Gill raker
Efferent branchial artery
Capillaries
Afferent branchial artery
Anterior gill arch
Afferent branchial artery

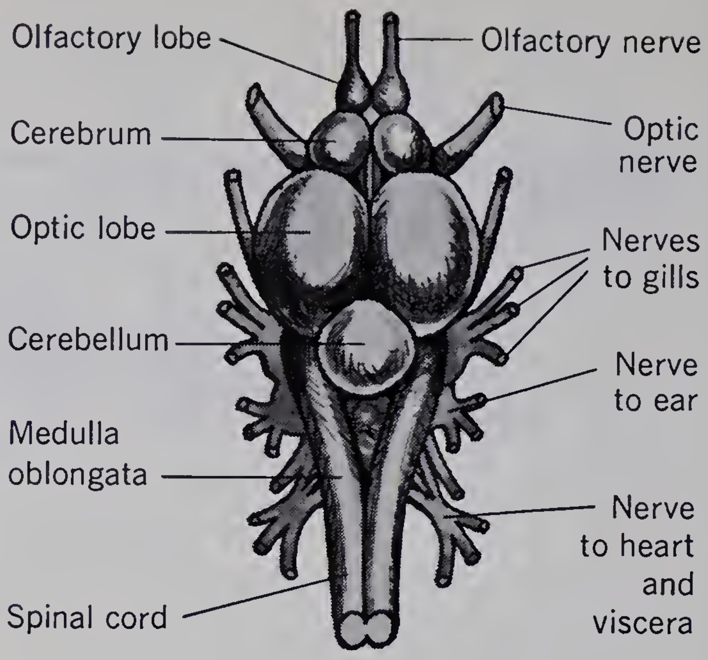
34-9 A sectioned view of a gill filament is shown at the top of the center drawing. The right-hand drawing shows a portion of a single filament, much enlarged.

blood, and oxygen is absorbed through the thin walls of the capillaries and filaments. Oxygenated blood returns to the gill arch and flows out the top of the gill through the ***efferent branchial artery*** to the dorsal aorta.

The fish requires a continuous flow of water over its gills. Water is drawn into the open mouth as the gill arches expand and enlarge the cavity of the pharynx. The edge of the operculum is pressed against the body as water is drawn in. The mouth is then closed, the gill arches contract, and the rear edge of the operculum is raised, thus forcing the water over the gill filaments and out of the gill chamber around the raised edge of the operculum. The forward motion of the fish aids this process when the fish is swimming.

The air bladder–pressure organ. A thin-walled sac, the ***air bladder,*** lies in the upper part of the body cavity of a fish. In fishes that swallow air it connects with the pharynx by a tube. In others it is inflated with gases (oxygen, nitrogen, and carbon dioxide) which pass into it from the blood. This sac acts as a float and adjusts the weight of the fish so that the weight of the animal equals the weight of the water it displaces. This equilibrium allows the fish to remain at any desired depth in the water with little effort.

Fishes live at various water levels at different seasons of the year. The air bladder adjusts to these variations by losing air to the blood or receiving additional air. When a fish is adjusted to deep water and is caught and brought to the surface suddenly, the air bladder expands and may push the esophagus into the mouth. One group of fishes known as *darters* has no air bladder. They sink to the bottom after each of their jerky swimming motions.



34-10 This is a dorsal view of the brain of a fish. Compare its development with that of some of the higher invertebrates.

The nervous system. The nervous system of the fish includes the brain, spinal cord, and the many nerves that lead to all parts of the body. The brain lies in a small bony cavity, the ***cranial cavity.*** It consists of five distinct parts (Fig. 34–10). At the anterior end are the ***olfactory lobes,*** from which the nerves, sensitive to odors, extend to the nostrils. Behind these lobes are the two lobes of the ***cerebrum,*** which control the voluntary muscles. In these lobes instincts are centered. Back of the cerebrum are the ***optic lobes,*** the largest of the fish's brain. Optic nerves lead from these lobes to the eyes. Behind them lies the ***cerebellum,*** which coordinates muscular activity, and finally the ***medulla oblongata,*** which controls the activities of the internal organs. The ***spinal cord*** passes down the back from the medulla and is encased in the vertebral column. Nerves connect the spinal cord with all the various parts of the body.

The fish's brain is not highly developed when compared to those of higher vertebrates. It shows, however, a great advance over the so-called brains of invertebrates. As you study the brains of other vertebrates, compare them with the fish brain. The same regions are present. There is, however, a gradual increase in the size of the cerebrum in proportion to the other brain regions as vertebrates become more advanced. As the cerebrum increases in size, there is a corresponding increase in nervous activity on higher levels, such as emotional responses, memory, and intelligence.

Sensations of the fish. The relatively large optic lobes of the brain indicate that fishes have a well-developed sense of sight. However, vision at even moderate water depths is greatly reduced because of insufficient light. Fishes are known to be nearsighted and probably do not see objects clearly at distances greater than a few feet. The fish eye focuses on objects by moving the nearly spherical lens forward or backward rather than changing the shape of the lens, as in our eyes. Scientists are not sure whether the fish sees colors or lives in a world of black, white, and shades of gray.

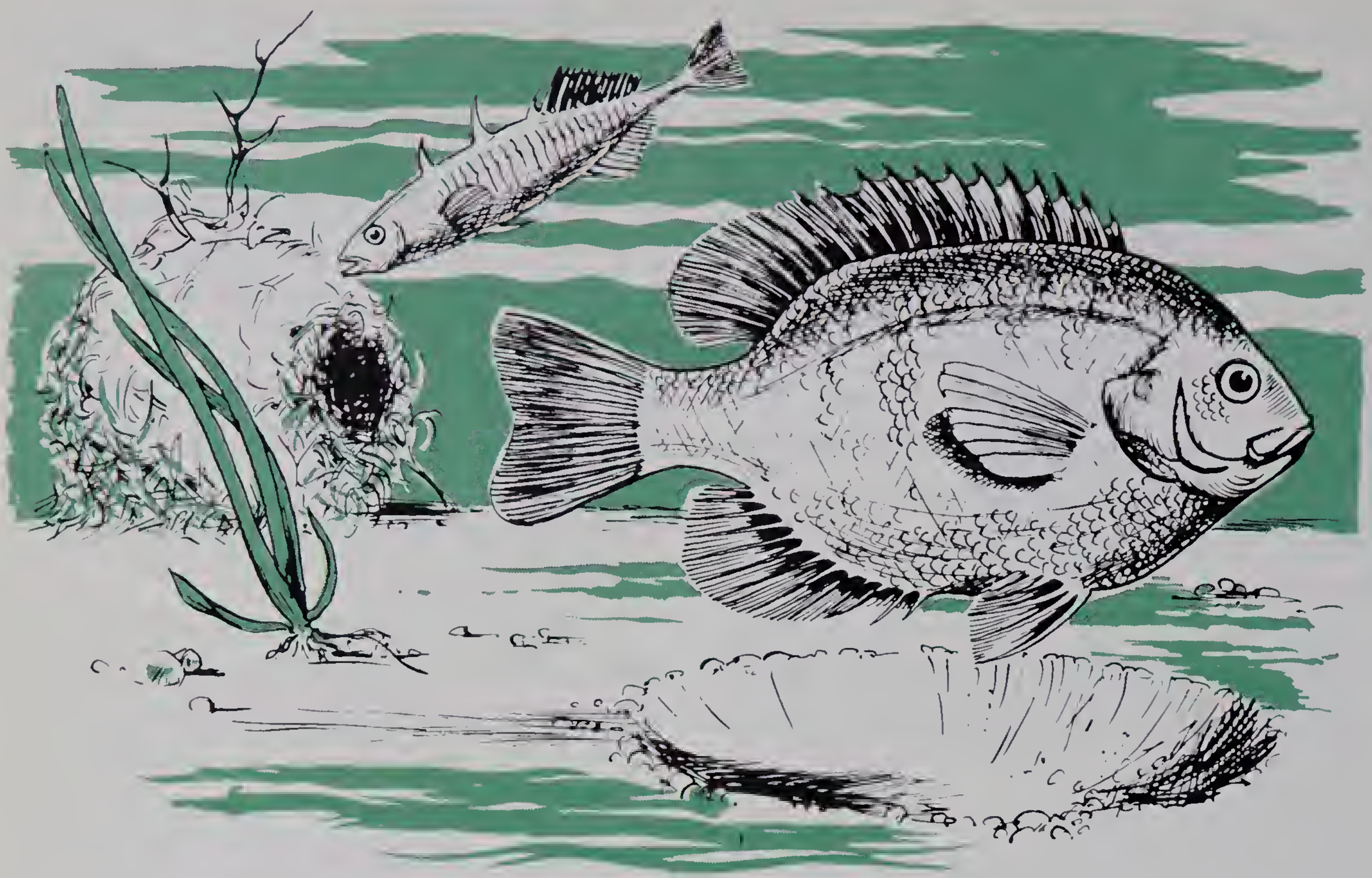
The internal ears are sensitive to vibrations of a lower frequency than those to which the human ear is sensitive. The bones of the skull, in which the ears are embedded, function efficiently in transmitting vibrations from the water to the sensitive ear structures.

Probably the fish's most acute sense is that of smell. Scientists have conducted extensive experiments to demonstrate the reaction of fishes to odors in the water. It has been found that fishes can distinguish the odors of many water plants, even when these plants are dipped for only a short time in pure water. Similarly, they can detect the odor of hands washed in a stream as well as the odors of many animals, especially mammals. Scientists now believe that odors direct fishes to feeding areas among water plants. It is possible, too, that salmon find the mouths of rivers and streams during the spawning season by the odors of plants living in these fresh-water bodies.

Reproduction in the fish. The reproductive organs, or ***gonads,*** lie in the posterior region of the body cavity. The opening from the gonads is just behind the anal opening.

Eggs develop in the ***ovaries*** of the female over a period of several months. As the eggs enlarge the ovaries swell, and may bulge the sides of the fish. Sperm develop in the paired ***testes*** of the male. Moments after the female lays her eggs, or ***spawns,*** the male swims over them and discharges a sperm-containing fluid called ***milt.*** Sperm swim to the eggs and fertilize them, and the development of the embryos begins. This development may require a few days to many weeks, depending on the species and the temperature of the water. The developing fish is nourished by a large quantity of nonliving material, the yolk, which is present in the egg. A part of the yolk known as the yolk sac remains attached to the young fish a short while after it has hatched.

The sunfish, like many fishes, deposits its eggs in a depression made in the bottom of a pond. After spawning, the male guards the nest, fighting off any intruder. The male stickleback makes a curious nest of bits of plants and rubble and drives the female into it for spawning. Then he chases her away and takes entire charge of the nest and eggs. Channel catfish spawn in holes in a bank or in a discarded can or other receptacle they have found on the bottom.



34-11 Some fish build nests on the shallow bottom. Compare the stickleback nest (left) consisting of strands of algae with that of the sunfish (right).

Guppies, mollies, platys, and swordtails are fresh-water tropical species commonly reared in home aquariums. These curious fish bear their young alive. The female retains the eggs within her body and receives sperm from the male during mating. The young fish develop internally and are brought forth alive.

Spawning is not a very efficient process. Many eggs never receive sperm. Large numbers are eaten by fishes and other aquatic animals before they have had a chance to hatch. After hatching, the young fish are in constant danger of being eaten by cannibalistic fishes and other animals. Regardless of the high mortality rate, the species survive because of the tremendous numbers of eggs laid. The number varies from about 500 in the trout to six or seven million in the codfish. Generally the number of eggs is proportionate to the amount of hazard encountered by the embryos and young fish.

IN CONCLUSION

No vertebrate has challenged the fish for supremacy in the water. A streamlined body with scales and fins, gills, and a two-chambered heart seem to be perfectly adapted to an aquatic environment. Alligators and water-dwelling snakes, swimming and diving birds, whales and seals share the water with fishes, but none of these higher vertebrates compares with fishes in importance.

In your study of the next group of vertebrates, the amphibians, you will find many fishlike animals. Others, such as the toad, are land dwellers. In studying these animals, you will find the basic structures of fishes carried to a higher degree of perfection in the development of land animals.

BIOLOGICALLY SPEAKING

air bladder
anal fin
atrium
branchial artery
bulbus arteriosus
cardinal vein
caudal fin
cerebellum
Chondrichthyes
chromatophores
countershading
cranial cavity
Cyclostomata
dorsal aorta
dorsal fin
gill arch
gill filament
gill raker
guanin crystals
isthmus
lateral line
medulla oblongata
milt
olfactory lobe
operculum
optic lobe
Osteichthyes
pectoral fin
pelvic fin
pericardial cavity
pyloric caecum
scales
sinus venosus
spawn
spinal cord
ventral aorta
ventricle

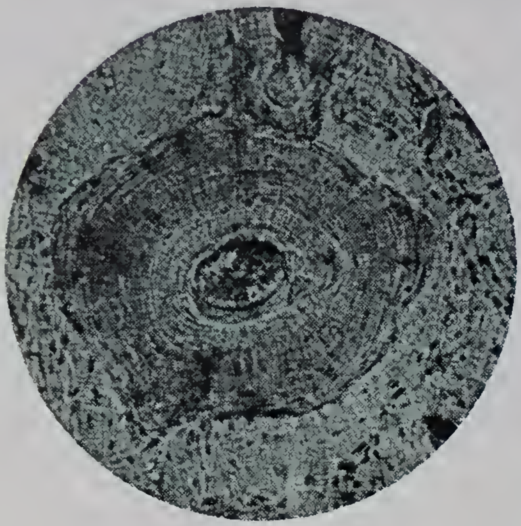
QUESTIONS FOR REVIEW

1. Describe the manner in which the sea lamprey attacks its prey.
2. What methods are being used to control sea lampreys?
3. What characteristics distinguish the shark from bony fishes?
4. How does the body slime protect a fish?
5. Describe countershading in the fish.
6. Name the fins of the yellow perch, and discuss the use of each.
7. Describe the organs of the alimentary canal of a fish in the order in which food passes through them.
8. Describe the structure of the fish heart.
9. Trace a drop of blood from the ventral aorta through a gill to the dorsal aorta, and describe changes in the blood during its circulation through a gill.
10. Locate and describe the air bladder. What is its function?
11. Name the various regions of the fish brain and the kind of nervous activity centered in each part.
12. Discuss the efficiency of the various sense organs of a fish.

APPLYING PRINCIPLES AND CONCEPTS

1. Explain how the body covering, limbs, and sense organs of a fish are ideally suited to life in the water.
2. Why does a fish die in the air, even though the air contains more oxygen than the water in which it lives.
3. Fishes lay enormous numbers of eggs, yet seldom overpopulate the waters in which they live. Give several reasons to account for this.

CHAPTER 35

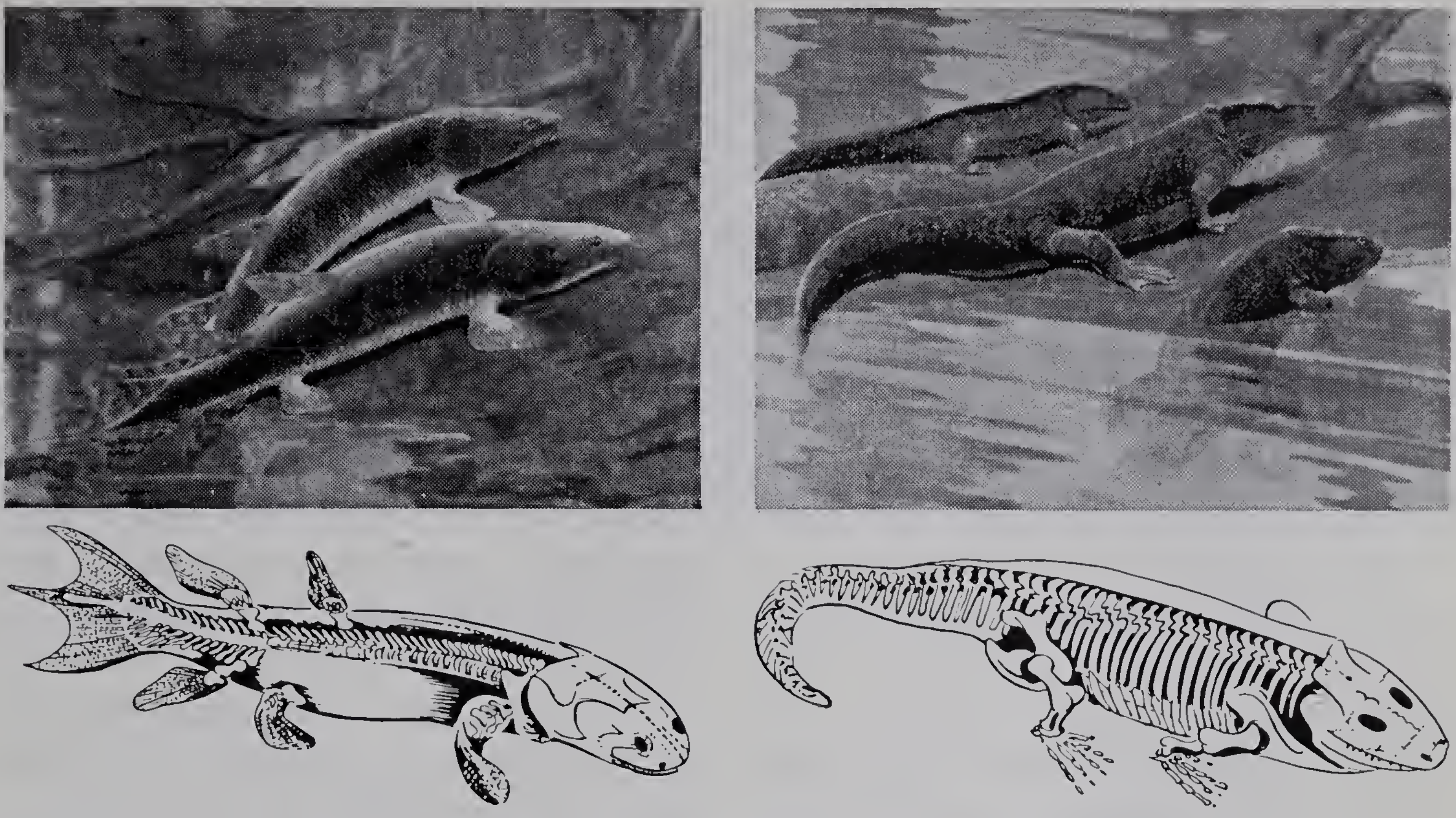


THE AMPHIBIANS

The arrival of the amphibians. Biologists believe that living things were confined to the water for millions of years. Then, at the end of the Devonian period (Fig. 13–1, page 183), changes must have occurred that resulted in the evolutionary development of life on land. The modern fishes we discussed in the last chapter all live in the water, of course, and breathe by gills. But remember the air bladder they use as an organ of balance? This organ is actually similar to an interesting adaptation that occurred in some of the early bony fishes. These fishes developed lunglike structures that enabled them to breathe air. There are even two types of these primitive lungfishes surviving today. They are found in Australia, Africa, and South America — all areas of seasonal drought. Functional lungs are absolutely necessary for their survival. When the droughts come, the lungfish digs a burrow in the bottom of the pool, where it lives curled up in a state of inactivity until the rains come and the water returns.

Another unique characteristic of the early lungfishes was their jointed, or lobed, fins somewhat resembling legs. Until about 25 years ago, it was thought that lobed fins had disappeared by the end of the Mesozoic Era. Fossils of lobe-finned fishes have been found in the rocks of the late Paleozoic and the Mesozoic Eras, but there is no trace of them in Cenozoic rocks. Biologists believed that they had become extinct some 70 million years ago. Then in 1939 a native South African commercial fisherman caught a type of fish he had never seen before. It was five feet long and was covered with large bluish scales. The fisherman gave the strange fish to a local museum where it was mounted. When it was shown to Dr. J. L. B. Smith of Rhodes University, he recognized it as a *coelocanth*, a lobe-finned fish that was supposed to have been long extinct. Since then many coelocanths have been caught in the waters between Madagascar and Mozambique. They retain lungs as outgrowths of the throat, and the fins resemble crude legs.

The development of lungs and leglike fins in some of the early bony fishes was probably an adaptation for survival. There were great climatic changes in the Devonian period. The ponds and streams often dried up or became stagnant, just as they do in the habitats of the modern lungfishes. Typical fishes could not have survived either condition. A fish that possessed some type of lung, however, could survive both drought and stagnancy. Likewise, a fish that possessed leglike fins could perhaps crawl away from a dried-up pond to a pond that still had water in it. This line of reasoning has led biologists to believe that the primitive lungfishes, with their



35-1 Above left: an artist's representation of how early lobe-finned fishes may have looked when they first came out on land. Above right: early amphibians. The drawings at the bottom show their skeletons, which have been reconstructed from fossil remains. Note the marked similarity between the two types of animals. (American Museum of Natural History)

lobed fins, were transitional forms between true fishes and amphibians.

The name *Amphibia* means, literally, "having two lives." It refers to the fact that, although the amphibians were able to develop some adaptations for life on land, they have never become completely free of water. They must still return to the water for reproduction, as their soft jellylike eggs would quickly perish on dry land. Furthermore, the young of all amphibians are completely water-bound for a period of time, and few adult amphibians can travel far from shore because they must keep their skins moist.

Amphibians were the dominant vertebrates into the Permian period. They became reduced in number near the end of the Paleozoic Era. The remaining large forms became extinct in the Triassic period. The amphibians of today, which include only three orders, appeared after the Triassic. They are not very significant vertebrates in our time.

Characteristics of the amphibians. The water-bound young of amphibians are fishlike; but they change to land-dwellers of quite different structure when adult. This series of changes is a metamorphosis, just as is the life history of certain insects. In this transition from water to land forms, many strange combinations of gills and lungs, fins and legs, occur. Gills are found on animals with legs, and fins are sometimes found on animals with lungs.

In general the Amphibia are distinct from other vertebrate animals in the following ways:

1. Body covered by a thin, flexible, and usually moist skin, without scales, fur, or feathers.
2. Feet, if present, often webbed.
3. Toes soft and lacking claws.
4. Immature or larval forms, vegetarian; adults, usually carnivorous.

5. Heart, two-chambered in larvae; three-chambered in adults; circulation well developed.
6. Eggs fertilized externally as soon as laid.
7. Metamorphosis from young to adult state.

Orders of Amphibia. The order *Apoda* (*ap*-oh-da) contains a few surviving legless amphibians of the tropics. These strange, wormlike creatures are often called *caecilians* (see-*sil*-ee-anz). A second order, ***Caudata*** (kaw-*day*-tuh), includes amphibians which have tails throughout life. Here we place the familiar salamanders and newts. The most familiar amphibians are the frogs and toads, members of the order ***Salientia*** (sal-ee-*en*-tee-a). Frogs and toads are different from other amphibians in that they lack tails in the adult stage. These animals, along with certain of the salamanders, undergo an interesting transition. They change from an aquatic life as a larva to a semiaquatic or terrestrial life as an adult.

The salamanders. Modern salamanders are very similar to their ancestors. The only evidence of evolution has been the replacement of cartilage with some bone in the skeleton. You are probably familiar with several of the salamanders, although you may have called them lizards. Many salamanders resemble lizards in general form. Both have elongated bodies, long tails, and short legs; but a salamander has soft, moist skin and lacks claws on its toes. The lizard has a scale-covered body and claws on its toes, characteristics of reptiles almost never found among the amphibians.

Salamanders have very little protection from their enemies. A few have skin glands which secrete bad-tasting substances. Others have color pigments that change with their surroundings. Salamanders cannot survive under dry conditions. This is why they are found under damp logs and stones or swimming about in water.

Salamanders range in size from a few inches to species several feet in length. The giant salamanders are represented in the United States by the *American hellbender*, which reaches a length of two feet or more. This large salamander, with loose grayish or reddish-brown skin, lives in the streams of the eastern United States. One of its relatives, the giant salamander of Japan, grows to five feet in length and is the largest living amphibian.

Another large salamander of the Middle West is the *mud puppy* or *water dog* (*Necturus*). Many an unsuspecting fisherman has been startled when he pulled one of these slimy salamanders from a mud-bottom stream in the late evening or night. The mud puppy may reach a length of two feet. It has a flattened, rectangular head, small eyes, a flattened tail, and two pairs of short legs. The most striking feature of its body is the pair of dark red, bushy gills attached at the base of the head just above the front legs. The presence of gills is a larval trait retained throughout life.

The *tiger salamander*, shown in Fig. 35–2, is found in most of the United States. It is one of the larger salamanders, reaching a length of six to ten inches. The bright yellow bars and blotches on a background color of dark brown give it its name. This salamander lives as an aquatic, gill-breathing larva for about three months, after which it leaves the water and lives on land. Both lungs and the thin, moist skin function in respiration during the land-dwelling stage.

35-2 The tiger salamander is widely distributed in North America. (American Museum of Natural History)

Certain tiger salamanders and others of the same genus remain aquatic throughout life and reproduce while still in the larval stage. Larval salamanders called *axolotls* (*ak*-sa-laht-ls) have long been known in Mexico and the southwestern part of the United States. Their curious characteristic of producing eggs or sperm in the larval stage once led biologists to believe that axolotls were separate species of salamander. But feeding experiments with thyroid gland tissue or thyroid extracts caused the animals to metamorphose into adults. This revealed them to be larval forms of the tiger salamander and some of its near relatives. Research revealed that the waters in which axolotls live are deficient in iodine. Iodine is essential for the production of a thyroid hormone needed for metamorphosis. Thus, axolotls are reduced to a larval existence because of a thyroid deficiency.

The *spotted salamander* might easily be confused with the tiger salamander, since the two species are similar in size and color. The spotted salamander, however, is shiny black with yellow spots. Its tail is round, while that of the tiger salamander is flattened laterally.

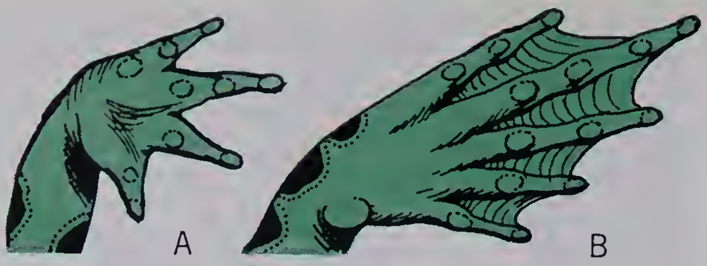
We often speak of the land-dwelling stage of small salamanders as newts. The *crimson-spotted newt* is especially interesting because of its "triple life." This small salamander hatches, usually in May, into a gill-breathing aquatic larva. After about two months, it changes to a land-dwelling stage with lungs. The coral-red color of this stage gives it the name red eft. One or two years later, the skin color changes to greenish-olive with crimson spots along the sides. The newt returns to the water and resumes aquatic life, breathing through its skin while under water and using its lungs at the surface.

The salamanders we have discussed are but a few of the many kinds you can find under piles of wet leaves, under rocks in stream beds, in abandoned wells, and in other moist places. Aquatic and land-dwelling stages of salamanders make ideal specimens for aquariums and moist terrariums. With a little coaxing they will eat meal worms or small insects from your hand.

Toads and frogs. The toads and frogs that lived previous to the Jurassic period all had elongated bodies and a long tail. Biologists believe that the great changes in body form were sudden. The most conspicuous change was the disappearance of a tail in the adult. Other less obvious changes made them better suited to life on land. The hind legs developed an extra joint and the ankle bones became elongated. These adaptations gave great power to the legs for leaping. Although the front legs were short, they were well suited for absorbing the shock of landing from a jump. Modern frogs and toads have wide mouths and front-hinged sticky tongues that can catch insects with lightning speed. These amphibians have lived for more than 200 million years and are found over most of the earth in many habitats. Biologists consider them among the most highly successful vertebrates.

Although there is great structural similarity, the frogs and toads differ in some respects in their anatomy and behavior. The toad is the most terrestrial of all amphibians, and after leaving the water early in life, never returns except to lay eggs. The toad starts life as a tiny black tadpole which soon grows legs, absorbs its tail, and hops onto land as a small, brown froglike creature with the warty skin characteristic of its kind. Adults of the common toad, *Bufo* (*byoo*-foh), are usually reddish-brown above and grayish-yellow beneath.

Toads sleep most of the day under rocks or boards but are active at night, snatching insects with their quick, sticky tongue. When disturbed they have no choice but to lie close to the ground. The toad has lost the swimming ability of other amphibians and on land moves with clumsy motion. In its in-between existence, this unfortunate creature lacks efficient locomotion in any environment and is able to survive only because of its protective coloration. Toads are widespread, but there are none in Australia.



35-3 The drawing shows the front (A) and the hind foot (B) of a frog. The fully webbed hind foot enables the animal to be an excellent swimmer.

Interesting amphibians are the tree frogs, of the genus *Hyla*. Most of them have amazing protective coloration, and several have the ability to change their color. Members of the genus that live in trees have a sticky disk on each toe which enables them to cling to vertical surfaces. One member of the genus *Hyla*, the well known spring peeper, lives in swamps and bogs rather than in trees.

Peeper eggs are laid in early spring, and the tiny ***tadpoles*** feed on algae and protozoans. The adults eat mosquitoes and gnats, which ought to give these frogs a place in our affection. A curious fact about their tadpole stage is that they often leave the water before the tail is entirely resorbed. Apparently they are able to breathe air earlier in their metamorphosis than the majority of other frogs.

The most common frog in the United States is the *leopard frog*, which inhabits nearly every pond, marsh, and roadside ditch. It frequently travels considerable distances from the water and may be seen hopping through the grass in meadows. Its name comes from the large dark spots, surrounded by yellow or white rings, that cover the grayish-green background color of the skin. The under surface of the leopard frog is creamy white, so that it blends with the light sky when viewed from below while it is resting on the surface of a pond.

The *bullfrog,* so named because its sound resembles the distant bellowing of a bull, is the most aquatic of all frogs. It seldom leaves the water except to sit on the bank of a lake or pond at night. The color of the bullfrog varies from green to nearly yellow, although the majority of them are greenish-brown. The under surface of the body is grayish white mingled with numerous dark splotches.

The large fully webbed hind feet of the bullfrog make it an excellent swimmer. These legs are well developed and ten inches long in large specimens. The bullfrog's diet is quite varied and includes insects, worms, crayfish, small fishes, and even an occasional duckling.

The economic importance of frogs. Much of the diet of frogs consists of insects. If frogs had no other value at all, this service alone would justify their protection. Many states have recognized their value and have passed laws regulating the hunting of frogs and prohibiting their capture during the breeding season.

The large hind legs of the bullfrog are a table delicacy. Frog farms, occupying large marshy areas, supply much of the demand for legs. The smaller species of frogs are widely used by fishermen for bait. As a biological specimen for dissection in the laboratory, the frog has long been a favorite. Since its internal organs are arranged similarly to those of the human body, dissecting a frog is an excellent introduction to human anatomy.

In recent years frogs have been used for pregnancy tests. Hospitals and clinics have become one of the best customers of frog collectors. With all of these uses, you can see that we must guard our frog population and conserve the lakes, marshes, and other watery habitats in which they thrive.

Anatomy of the frog. Facing page 488 you will find a leopard frog as seen by the "Trans-Vision" process. The first page (Plate I) shows the lower side of the frog. The upper side is shown on the last page (Plate VIII). As you turn the pages between these, you will see the internal organs at various depths of the body. Pages on the right show the ventral side of the organs. The transparencies on the left show the dorsal side of the organs.

As we discuss the structure of the frog — its form and body covering, legs, head structure, and internal organs — find the various organs in the plates of the "Trans-Vision."

External structure of the frog. The frog's body is short, broad, and angular. It lacks the perfect streamlined form we find in the fishes. For this reason the frog is not the graceful swimmer the fish is, nor does its awkward hopping on land compare with the graceful movement of most other land animals. This is the price the frog must pay for living in two environments.

The skin is thin, moist, and loose. It is richly supplied with blood vessels. Glands in the skin secrete mucus, which reaches the surface through tiny tubes. This slimy substance makes the frog difficult to hold. The skin lacks any protective outgrowths such as the scales and plates of fishes and reptiles.

Adaptations of the frog's legs. The front legs of the frog are short and weak. Each has four inturned toes with soft rounded tips, as shown in Fig. 35–3. The front feet lack a web and are not used for swimming. The inner toe of a male frog is enlarged, especially during the breeding season. The front legs are used to prop up the body on land and to break the fall after a leap.

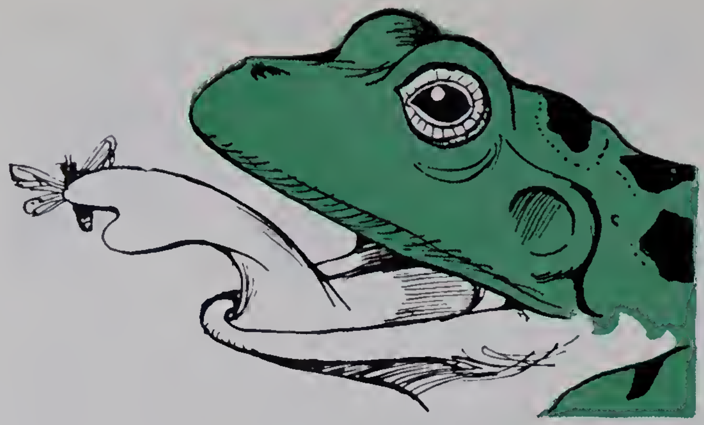
The hind legs are enormously developed and adapted in several ways for swimming and leaping. The thigh and calf muscles are very powerful. The ankle region and toes are greatly lengthened, forming a foot that is longer than the lower leg. A broad flexible ***web membrane*** lies between the five long toes, making the foot an extremely efficient swimming organ. The hind legs fold against the body when the frog is resting on land. In this position the animal is ready for a sudden leap.

The head and its structure. Probably the most noticeable structures of the head are the eyes. The eyes of frogs and toads are among the most beautiful of the animal kingdom. The colored iris surrounds the elongated black pupil opening. Muscles attached to the eyeball rotate the eye in its socket. The frog's eyes bulge above the head, but can be pulled into their sockets and pressed against the roof of the mouth. In this position they help to hold food in the mouth.

When the eyes are pulled down, the upper and lower eyelids fold over them. The bulging eyes serve as periscopes when the frog is under water. It can float just below the surface with its eyes above water. A third eyelid, the ***nictitating*** (*nik*-tih-tay-ting) ***membrane,*** joins the lower lid. This thin covering keeps the eyeball moist on land and serves as a protective covering when the frog is under water.

The nostrils are located far forward on top of the head, allowing the frog to breathe air with all but the top of the head submerged.

The frog has no external ears. The eardrum, or ***tympanic*** (tym-*pan*-ik) ***membrane,*** lies on the surface of the body just behind the eyes. The cavity of the middle ear lies just below the tympanic membrane. A canal, or ***Eustachian*** (yoo-*stay*-kee-un) ***tube,*** connects each middle ear with the mouth cavity. The inner ears are embedded in the skull.



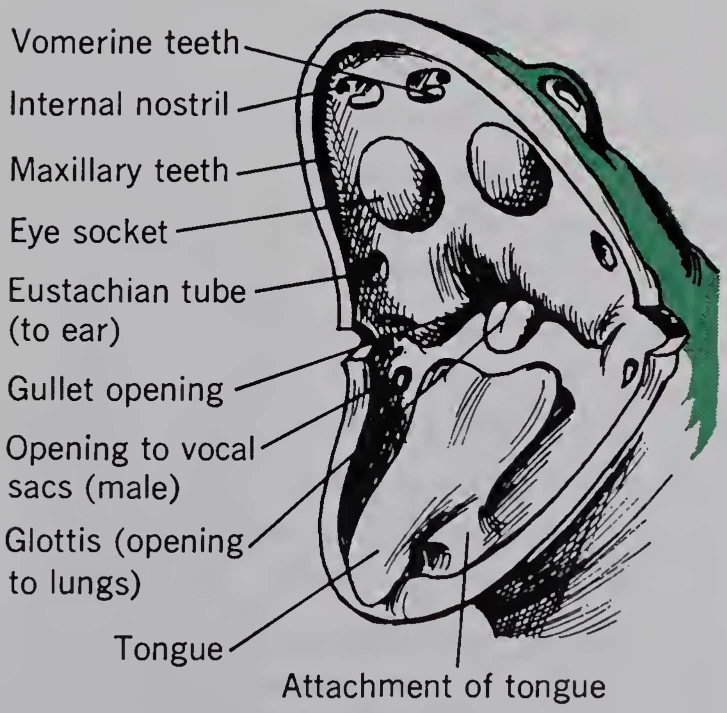
35-4 The frog's tongue is especially well adapted for catching insects, because it is both flexible and sticky. Note how it is attached at the front of the mouth.

The frog's mouth — an efficient insect trap. The frog's mouth extends literally from ear to ear. If you watch a frog catch a fly, you will discover why the mouth must be so large — it serves as an insect trap. The thick, sticky tongue is attached at the front in the floor of the mouth and has two projections on the free end (Fig. 35–4).

When a frog catches an insect, the mouth opens wide and the tongue flips over and out. The insect is caught on the tongue surface and is thrown against the roof of the mouth. The mouth snaps shut and the insect is swallowed. This happens so quickly you can hardly see it. Two ***vomerine teeth,*** projecting from bones of the roof of the mouth, aid in holding the prey. The frog has no teeth on the lower jaw. Small, conical ***maxillary teeth,*** projecting from the upper jawbone, also aid in holding prey.

Inside the frog's mouth, as shown in Fig. 35–5, you can see various openings. The internal nostril openings lie in the roof near the front, on either side of the vomerine teeth. Far back on the sides of the roof of the mouth are the openings of the ***Eustachian tubes.*** In a corresponding position in the floor of the mouth of a male frog are openings to the ***vocal sacs.*** When a frog croaks, air is forced through these openings into bladderlike sacs which expand between the ears and the shoulders. This action adds resonance and volume to the sound. When the frog croaks under water, air is forced from the lungs, over the vocal cords, into the mouth and back to the lungs. The throat contains two single openings — a large ***gullet opening*** leads to the stomach; below the gullet opening is the slitlike ***glottis,*** the opening to the lungs.

Digestive system of the frog. While the diet of the adult leopard frog consists largely of insects and worms, it can swallow even larger prey because of its large, elastic ***gullet.*** The short gullet leads to the ***stomach,*** an oval enlargement of the food tube. The stomach is large at the gullet and tapers at the lower end. Here the stomach joins the small intestine at a point referred to as the ***pylorus.*** The stomach content passes into the small intestine through a muscular ***pyloric valve.***



35-5 Here you see a diagram of the internal structure of the frog's mouth. Its rather large size is an adaptation for the obtaining of food.

The ***small intestine*** lies in several loops supported by a fanlike membrane, the ***mesentery.*** The small intestine of the frog is proportionally longer than that of the fish. At its lower end, the small intestine leads to a short, broad ***colon,*** or *large intestine.* The lower end of the large intestine, leading to the anal opening, is termed the ***cloaca*** (kloh-*ay*-ka). The walls of the cloaca contain openings of the ureters from the kidneys, the urinary bladder, and the oviducts of the female frog.

The large three-lobed ***liver*** partially covers the stomach. It is a storehouse for digested food and also a digestive gland which secretes bile. The bile collects in the ***gallbladder*** on the dorsal side of the liver and passes into the upper small intestine through the ***bile duct.*** The ***pancreas,*** a second digestive gland, lies inside of the curve of the stomach. Pancreatic fluid passes into the small intestine with bile through the bile duct. Both of these fluids are necessary for intestinal digestion. ***Mucous glands*** in the walls of the stomach and intestine secrete mucus, a lubricating fluid. Tiny ***gastric glands*** in the walls of the stomach secrete gastric fluid, another vital digestive fluid.

We find in the frog a digestive system like that of other vertebrates. A long food tube, or ***alimentary canal,*** is composed of specialized regions where digestion and absorption of digested food take place. The length of the alimentary canal increases the general efficiency of both these processes tremendously.

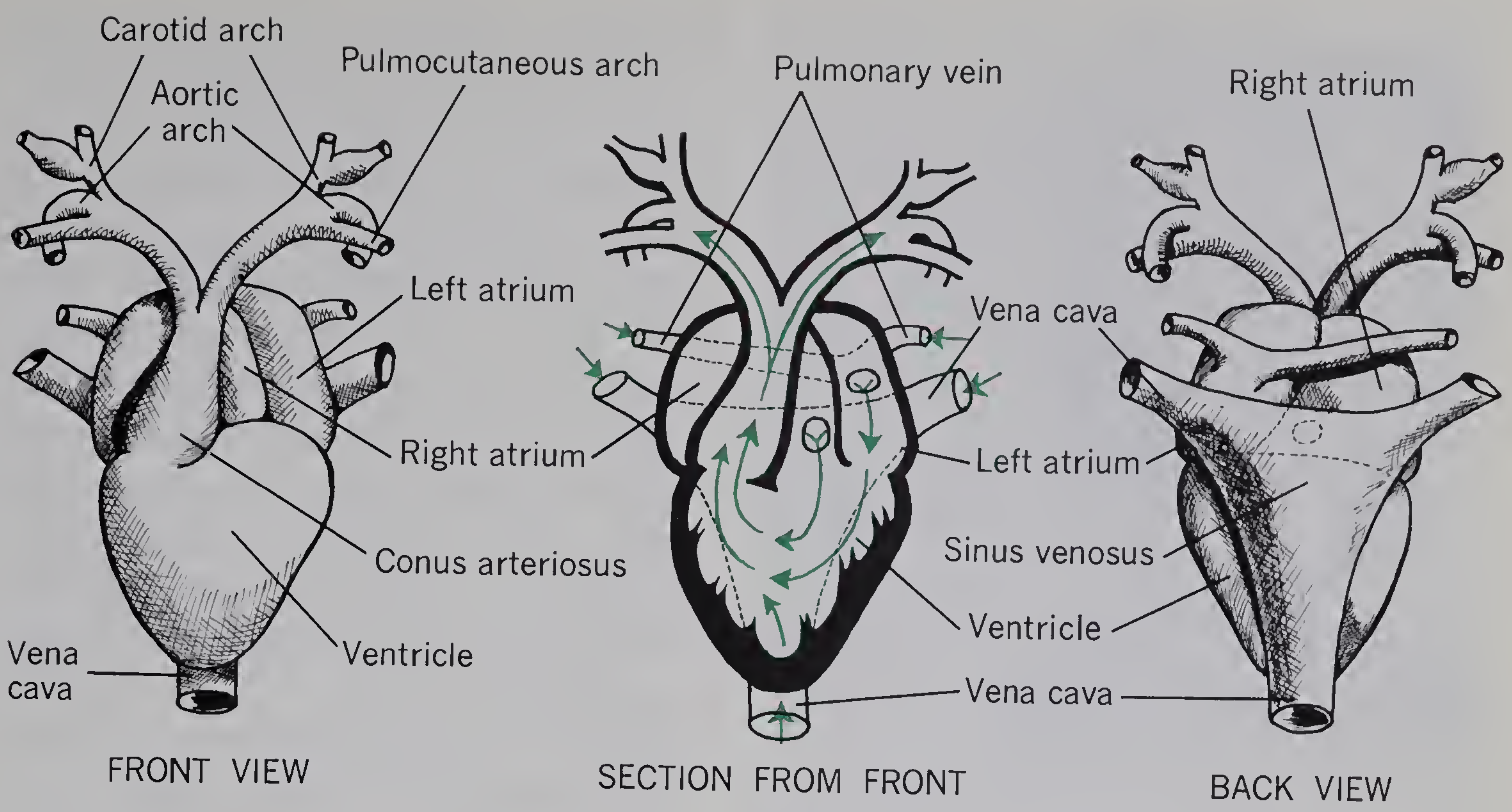
The respiratory system of the frog. Have you ever wondered how the frog, an air breather, can stay under water for long periods and lie buried in the mud at the bottom of a pond through a winter hibernation? The answer lies in skin respiration. The skin of the frog and other amphibians is thin and richly supplied with blood vessels. While the frog is in the water, dissolved oxygen passes through the skin to the blood. Carbon dioxide is given off. Respiration through the skin supplies the frog's needs as long as it is quiet. During hibernation the body processes continue at a very slow rate. The oxygen need is very low. However, body activity such as swimming greatly increases the need for oxygen, and the skin cannot supply enough. The frog then comes to the surface and breathes air.

We inhale and exhale air by increasing and decreasing the size of our chest cavities. This is accomplished by movement of the ribs and diaphragm, a muscular partition at the bottom of the chest cavity. The frog has no diaphragm and therefore has no chest cavity; nor does the frog have ribs. When the frog lowers the floor of its mouth with the mouth closed, air rushes in through the open nostrils into the partial vacuum. When the floor of the mouth springs up, air passes out through the nostrils.

The lining of the mouth is well adapted for respiration because it is thin, moist, and richly supplied with blood vessels. At this point we must distinguish mouth breathing from lung breathing. The frog may pump air in and out of its mouth for some time without using its ***lungs*** at all. When the lungs are used, the nostrils are closed by flaps of skin as the floor of the mouth rises. The glottis opens and admits air to the windpipe, or ***trachea***, and lungs. Then, with the nostrils still closed, the mouth is thrust down and air passes out of the lungs into the partial vacuum. The upthrust of the mouth immediately following this seems to be higher than usual and forces air back into the lungs. After exchanging air once or twice from mouth to lungs and lungs to mouth, the frog resumes mouth breathing through the open nostrils.

Thus the frog depends on its lungs only to supplement mouth breathing of air. As you might expect, the lungs are small when compared with higher animals which depend entirely on lung breathing. They are thin-walled sacs that lack the spongy tissue ours have.

The circulatory system. The circulatory system of the frog shows an advance over that of the fish and a step toward the complex system of the higher vertebrates. One of these advances is a three-chambered heart, consisting of two ***atria*** (*auricles*) and a muscular ***ventricle*** (Fig. 35–6). Deoxygenated blood enters the right atrium from various parts of the body. Blood from the lungs, which is oxygenated when the lungs are in use, enters the left atrium. The atria contract simultaneously and fill the ventricle. Contraction of the ventricle forces blood out a large vessel, the ***conus arteriosus***, which lies against the front side of the heart. This large vessel divides at once into two branches like a letter Y. Each of these branches divides again into three arteries. The anterior pair are the ***carotid arches***, which transport blood to the head. The middle pair, or ***aortic arches***, bend to the right and left around the heart and join just below the liver to form the ***dorsal aorta.*** This great artery supplies the muscles, digestive organs, and other body tissues. The posterior ***pulmocutaneous arches***



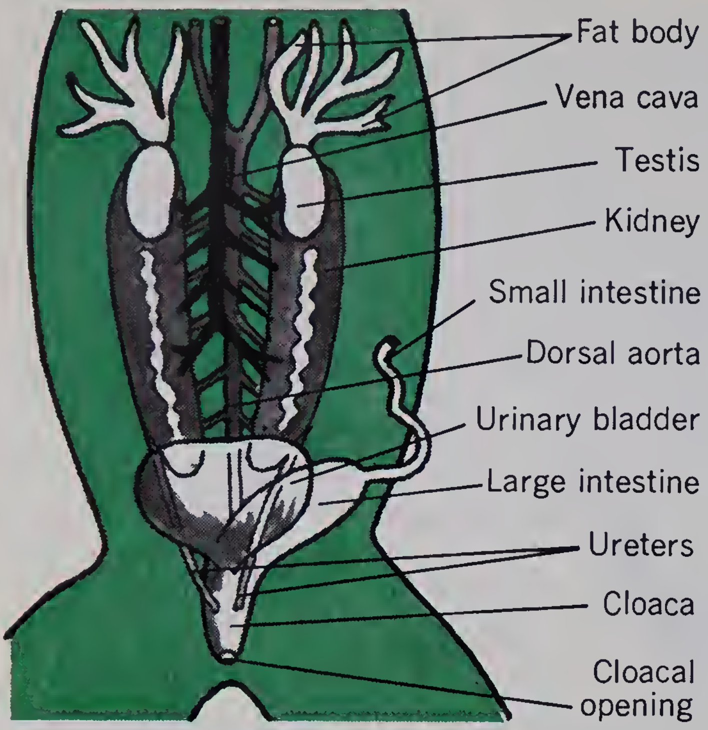
35-6 In the frog heart, three branches of the vena cava lead to the right atrium. Pulmonary veins lead from the lungs to the left atrium. Blood from both these chambers passes through the conus arteriosus. This large vessel divides above the heart and gives rise to the right and left carotid, aortic, and pulmonary arches. The right-hand drawing shows the heart viewed from the back side, where the venae cavae enter the sinus venosus and the pulmonary veins enter the left atrium.

form arterial branches that transport blood to the lungs, skin, and mouth.

Blood returning from the body is laden with carbon dioxide and other cell wastes and has been relieved of much of its oxygen. Three large veins, the ***venae cavae***, join a triangular, thin-walled sac, the ***sinus venosus***, on the back side of the heart, which in turn empties into the right atrium. Part of the blood returning to the heart from the lower parts of the body flows through vessels of the digestive organs and absorbs digested food. This blood flows through the ***hepatic portal vein*** to the liver on its way to the right atrium. During each complete circulation of blood, some of the blood passes through the kidneys where water and nitrogen-containing wastes from cell activity are removed.

The frog's circulatory system shows several advances over that of the fish. Blood passes through the two-chambered heart of the fish only once in making a round trip through the body. The three-chambered frog heart receives blood from both the body and the lungs, and pumps blood to the head and body as well as to the various centers where respiration takes place.

The excretory system of the frog. The frog's skin is a vital organ of excretion since it is here rather than in the mouth or lungs that most of the carbon dioxide is discharged from the blood. The liver removes certain wastes and eliminates them with bile or converts them for removal by the kidneys. The large intestine eliminates undigested food and other wastes. However, the ***kidneys*** are the principal organs of excretion. They receive wastes from the blood, which flows into them through the ***renal arteries*** and out through the ***renal veins.*** The kidneys are large, dark red organs lying on either side of the spine against


Fat body
Vena cava
Testis
Kidney
Small intestine
Dorsal aorta
Urinary bladder
Large intestine
Ureters
Cloaca
Cloacal opening

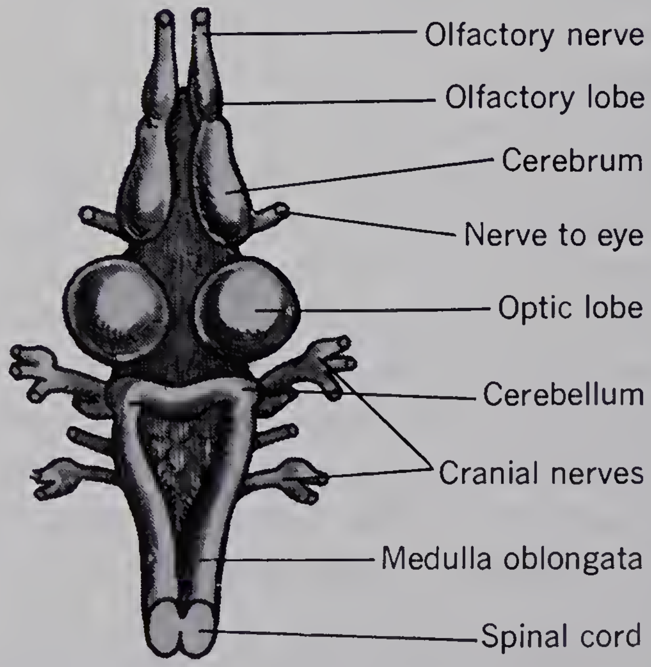
35-7 The urogenital organs of a male frog.

the back body wall. Urine collects in the kidneys and flows to the cloaca through tiny tubes, the ***ureters*** (yoo-*ree*-terz), that you can see in Fig. 35–7. The urine may be excreted immediately, or it may be stored after being forced into the urinary bladder through an opening in the cloaca.

The frog's nervous system. The frog's brain shows a considerable advance over that of the fish. ***Olfactory lobes*** lie at the anterior end of the brain (Fig. 35–8). The elongated lobes of the ***cerebrum*** are proportionally larger than those of the fish. Posterior to these are the prominent ***optic lobes.*** The ***cerebellum*** is just behind the optic lobes. In the frog it is a small band of tissue lying at right angles to the long axis of the brain. The ***medulla oblongata*** lies posterior to the cerebellum and joins the short, thick ***spinal cord,*** which extends down the back. Pairs of ***spinal nerves*** branch from the cord and pass to various parts of the body through openings between the vertebrae. Extending from the brain are ten pairs of ***cranial nerves.***

The reproductive system. Since the reproductive organs of the frog are internal, it is difficult to distinguish the sexes except during the breeding season, when the thumb of the male is enlarged. The male reproductive organs are two oval, creamy white or yellowish ***testes.*** They lie in the back, one on each side of the spine, above the anterior region of the kidneys. Sperm develop in the testes and pass through tubes, the ***vasa efferentia*** (*vah*-sah ef-fur-*ent*-shah), into the kidneys. When the sperm are discharged, they pass through the ureters and on into the cloaca. Some species of frogs have an enlargement, the ***seminal vesicle,*** at the base of each ureter.

Eggs develop in a pair of large, lobed ***ovaries*** in the female, which attach along the back above the kidneys. During the breeding season, the eggs enlarge, burst the thin ovary walls and are freed into the body cavity. Movement of the abdominal muscles works the eggs toward the anterior end of the body cavity. Here are funnel-like openings of the long coiled ***oviducts.*** The eggs are fanned into the oviduct openings by


Olfactory nerve
Olfactory lobe
Cerebrum
Nerve to eye
Optic lobe
Cerebellum
Cranial nerves
Medulla oblongata
Spinal cord

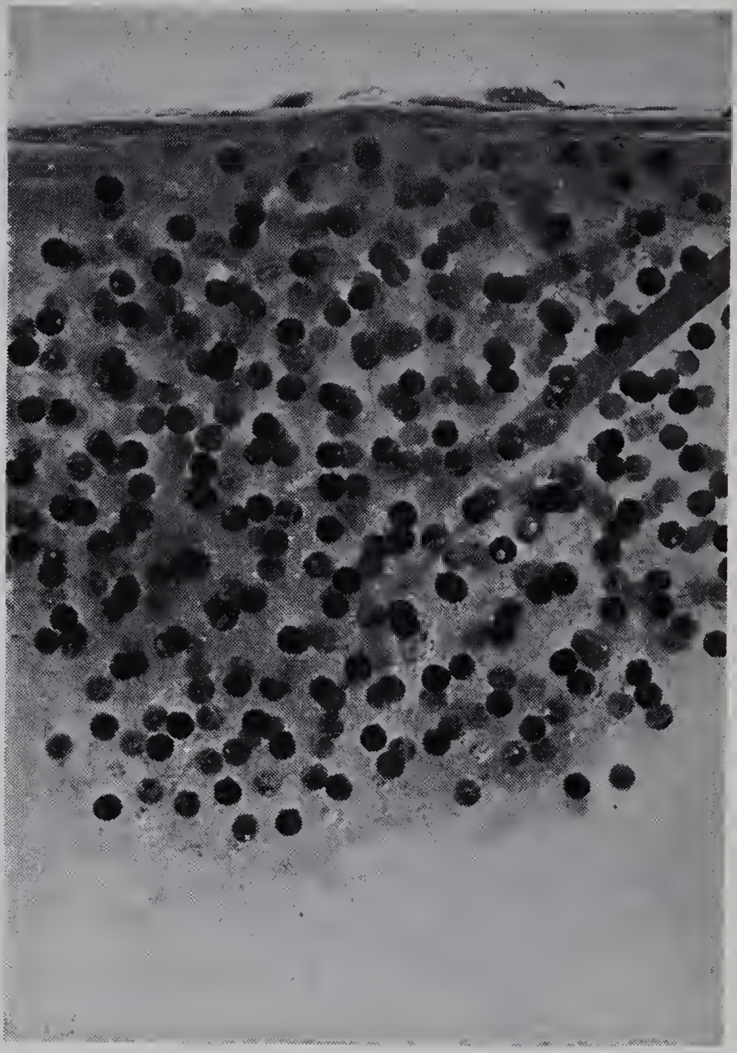
35-8 The brain of a frog. Compare this with that of the fish in the previous chapter.

cilia. Near their opening into the cloaca, the walls of the oviducts secrete a gelatinous substance that surrounds each egg. At the base of each oviduct is a saclike ***uterus*** in which the eggs are stored until they are laid through openings into the cloaca.

Fertilization and development of the eggs. The female leopard frog usually lays her eggs some time between the first of April and the middle of May. The male clasps the female at the time the eggs are laid. The male may also press down on the female, thus helping to lay the eggs. As the eggs pass from the cloaca of the female, the male spreads sperm over them. As a result of this direct fertilization, most of the eggs receive sperm.

The jellylike coat that surrounds each egg swells in the water and joins the eggs in a rounded, gelatinous mass. In this clump the eggs look like small beads, each surrounded by a transparent covering (Fig. 35–9). Not only does the jelly protect the eggs from injury, but it makes them more difficult for a hungry fish to eat. Also it serves as the first food for the young tadpole.

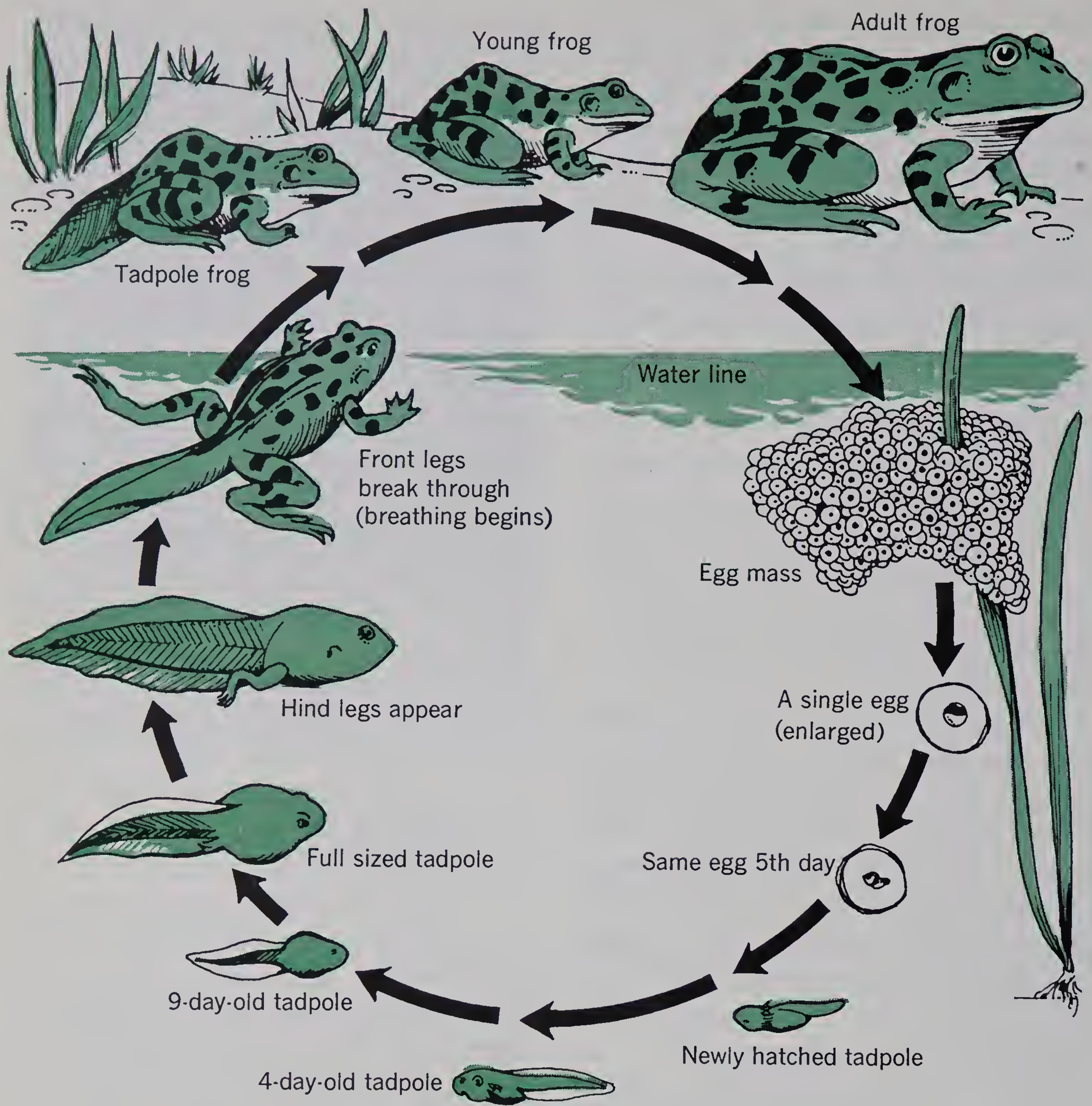
The frog egg is partly black and partly white. The white portion is the yolk, or stored food material, which will nourish the tadpole during development. The dark portion contains the living protoplasm of the egg and a dark pigment. The yolk is heavier than the rest of the egg, causing the eggs to float in the water dark side up. The black pigment on the upper side absorbs heat from the sun while the lighter lower half blends in with the light from the sky and makes the eggs hard to see from below. The gelatinous covering holds much of the heat in the mass. After eight to twenty days, depending on the weather conditions and water temperature, the tadpole hatches and wiggles away from the egg mass.



35-9 This mass of frog's eggs is lodged in the leaves of a plant growing in a shallow pond. (Hugh Spencer)

From tadpole to adult – the metamorphosis of the frog. Just after hatching, the tadpole is a tiny, short-bodied creature with a disklike mouth. It clings to the egg mass or to a plant as shown in Fig. 35–10. Yolk stored in the body nourishes the young tadpole until it starts to feed. Soon after hatching, the body lengthens and three pairs of external gills appear at the sides of the head. The tail lengthens and develops a caudal fin. The mouth opens and the tadpole begins scraping the leaves of water plants with horny lips.

Soon after the tadpoles become free swimmers, the horny lip disappears. A long, coiled digestive tract develops, and the tadpole starts living on vegetable scums. Gradually a flap of skin grows


Young frog
Adult frog
Tadpole frog
Water line
Front legs break through (breathing begins)
Egg mass
Hind legs appear
A single egg (enlarged)
Full sized tadpole
Same egg 5th day
9-day-old tadpole
Newly hatched tadpole
4-day-old tadpole

35-10 This diagram shows the life history of the frog. The length of time for metamorphosis varies in different species of frogs.

over the gills (now only two pairs) and leaves a small opening on the left side through which water passes out of the gill chambers. At this stage the tadpole is a fishlike animal with a lateral line, fin, two-chambered heart, and a one-circuit circulation. The animal also has a relatively long, spirally-coiled intestine.

The change to an adult frog is remarkable. The hind legs appear first. The front legs begin to form at about the same time but do not appear for some time. They remain hidden under the operculum. Soon after the appearance of the front legs, the tadpole then starts resorbing (not shedding or eating) its tail. Late in the metamorphosis, the tadpole's mouth broadens and teeth develop. While these external changes are taking place, equally important internal changes occur. A saclike chamber, resembling the swim bladder of the fish, forms back of the throat. This divides into two sacs, which become the lungs. The heart becomes three-chambered, and the gill arteries change to the carotids, aortic arches, and the pulmocutaneous arteries. The gills stop functioning and the tadpole comes to the surface frequently to gulp air. The thin skin and broad, flat tail still play an important role in respiration during this extremely critical time in its life.

Even before the tail is entirely resorbed, the tadpole leaves the water and comes to land as a young frog. Development from this stage to the full-grown adult frog usually requires about a month. The metamorphosis of the leopard frog varies from 60 to 90 days. Full-grown adults usually appear about the first of July. The bullfrog usually spends two winters as a tadpole, and its entire metamorphosis may last as long as three years.

Regeneration in Amphibia. Many amphibians, especially salamanders, have a remarkable ability to regenerate lost or injured body parts. A foot, a portion of a limb, or part of the tail may be lost in escaping from an enemy. Such amputated organs may be regenerated rapidly. The tadpole stages of frogs and toads also have regenerative powers, especially in the early phases. This ability to regenerate disappears as the tadpole matures and is lacking entirely in the adult stage of all genera and species of frog and toad.

Hibernation and estivation in the frog. The frog, as well as the fish and reptile, are "cold-blooded" vertebrates. This does not mean that their blood is always cold. It means that the body temperature of these animals varies with the temperature of the surroundings. Man maintains a constant average body temperature of about 98.6° F by regulating the rate of food oxidation and resulting heat release in the tissues as well as heat loss from the body surface. The cold-blooded vertebrates carry on much slower oxidation and do not maintain a relatively constant body temperature.

With the coming of fall and the seasonal lowering of temperature, the body temperature of the frog drops to the point where it can no longer be very active. It buries itself in the mud at the bottom of a pond or finds shelter in some other protected place in the water. Heart action slows down to a point at which blood hardly circulates in the vessels. The moist skin supplies the greatly reduced oxygen necessary for keeping alive. The tissues are kept alive by the slow oxidation of food stored in the liver and in the mass of yellow in the ***fat bodies*** attached above the kidneys in most frogs. Nervous activity almost ceases, and the frog lies in a stupor. This is the condition of the frog during ***hibernation***, or winter rest. With the coming of spring, the warm days speed up body activity and the frog gradually resumes physiological and functional activities of normal life.

The hot summer months bring other problems. Lacking a device for cooling the body, the frog must escape from the extreme heat. It may lie quietly in deep cool water or bury itself in the mud at the bottom of a pond, in the condition of summer inactivity referred to as ***estivation.*** Many smaller ponds dry up during midsummer, and the frogs and other cold-blooded animals survive only by burying themselves in the mud and estivating. With the coming of cooler weather and the return of water to the pond, they come out of estivation and continue normal activity until hibernation.

IN CONCLUSION

The frog has long been a favorite subject for biological study. Each individual frog passes through various stages of development, from a fishlike larva to an adult terrestrial amphibian. In the adult stage the organs and systems of the frog are complex and efficient. Biologists still marvel at its three-chambered heart with its complicated valves and arteries. Lungs, mouth, and skin together compose an efficient respiratory team. Of course, if the skin is to be used in respiration, it must be thin and moist. Thus the frog may not leave the water or a moist environment entirely. Amphibians never did become successful on land, and today they form an insignificant part of the vertebrate population.

In the next class of vertebrates, you will find animals which, while similar to the frog in many ways, are much better suited to life on land.

BIOLOGICALLY SPEAKING

alimentary canal
Amphibia
aortic arch
Apoda
bile duct
carotid arch
Caudata
cloaca
colon
conus arteriosus
cranial nerves
estivation
Eustachian tube
fat body
gallbladder
gastric glands
glottis
gullet
hepatic portal vein
hibernation
maxillary teeth
mesentery
mucous glands
nictitating membrane
oviduct
pancreas
pulmocutaneous arch
pyloric valve
pylorus
renal vessels
Salientia
seminal vesicle
sinus venosus
spinal nerves
tadpole
trachea
tympanic membrane
ureters
uterus
vasa efferentia
vena cava
vocal sacs
vomerine teeth
web membrane

QUESTIONS FOR REVIEW

1. Why do biologists believe that the early lobe-finned lungfishes were amphibian ancestors?
2. What characteristics of amphibians distinguish them from other living vertebrates?
3. How many orders of amphibians are represented by living members today?
4. In what ways do salamanders resemble lizards? Name several characteristics that make them different from lizards.
5. Explain why the axolotl does not undergo metamorphosis.
6. Describe the "triple life" of the crimson-spotted newt.
7. Describe the manner in which a frog catches a flying insect.

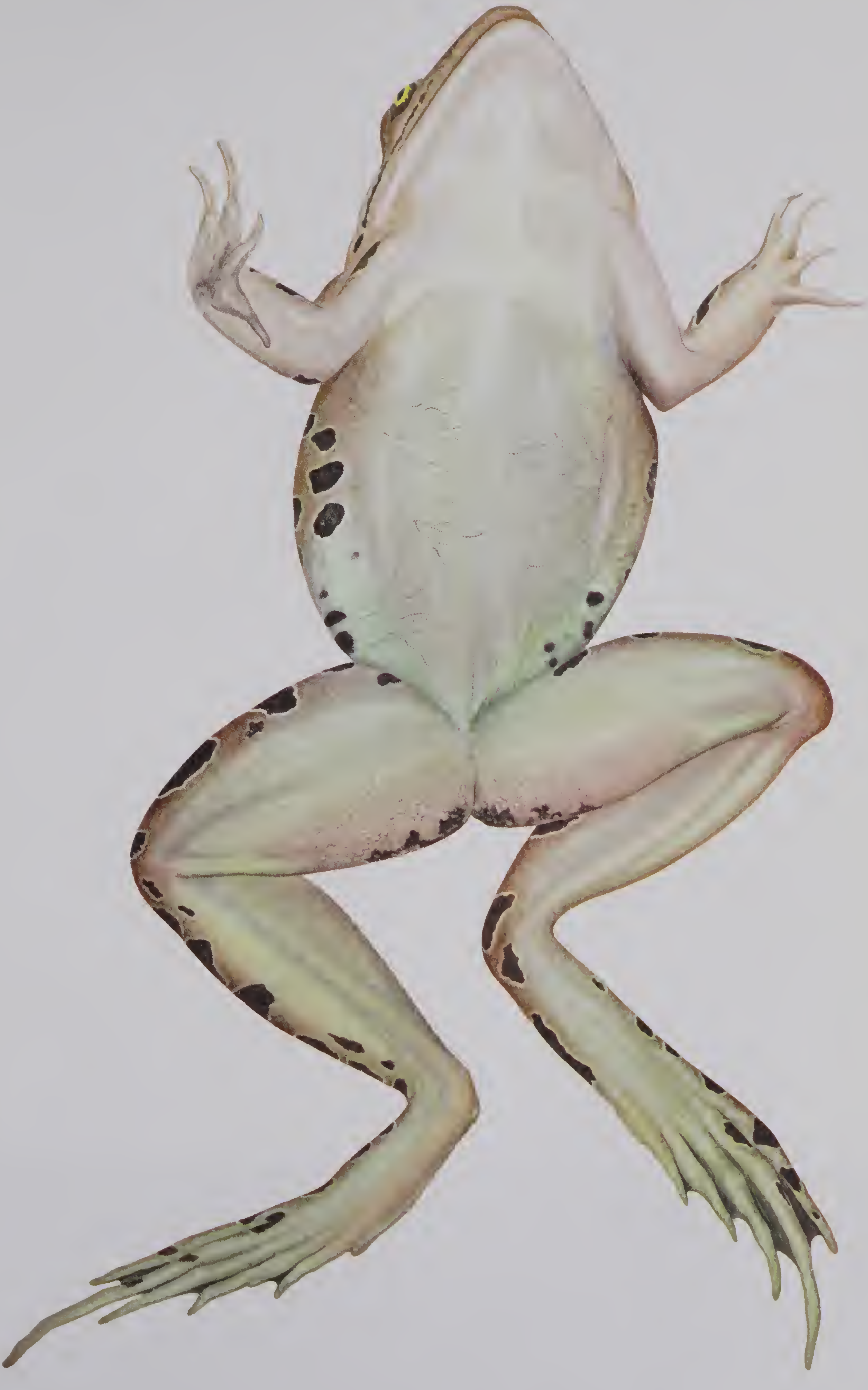
8. How can a frog croak under water?
9. Name the organs forming the alimentary canal of a frog, in the order in which they receive food.
10. Name the chambers of the frog's heart.
11. What three arterial branches carry blood from the great artery leading from the frog's heart?
12. How is urine conducted from the frog's kidneys to the cloaca and bladder?
13. Discuss in order of occurrence the changes during the development of a tadpole.

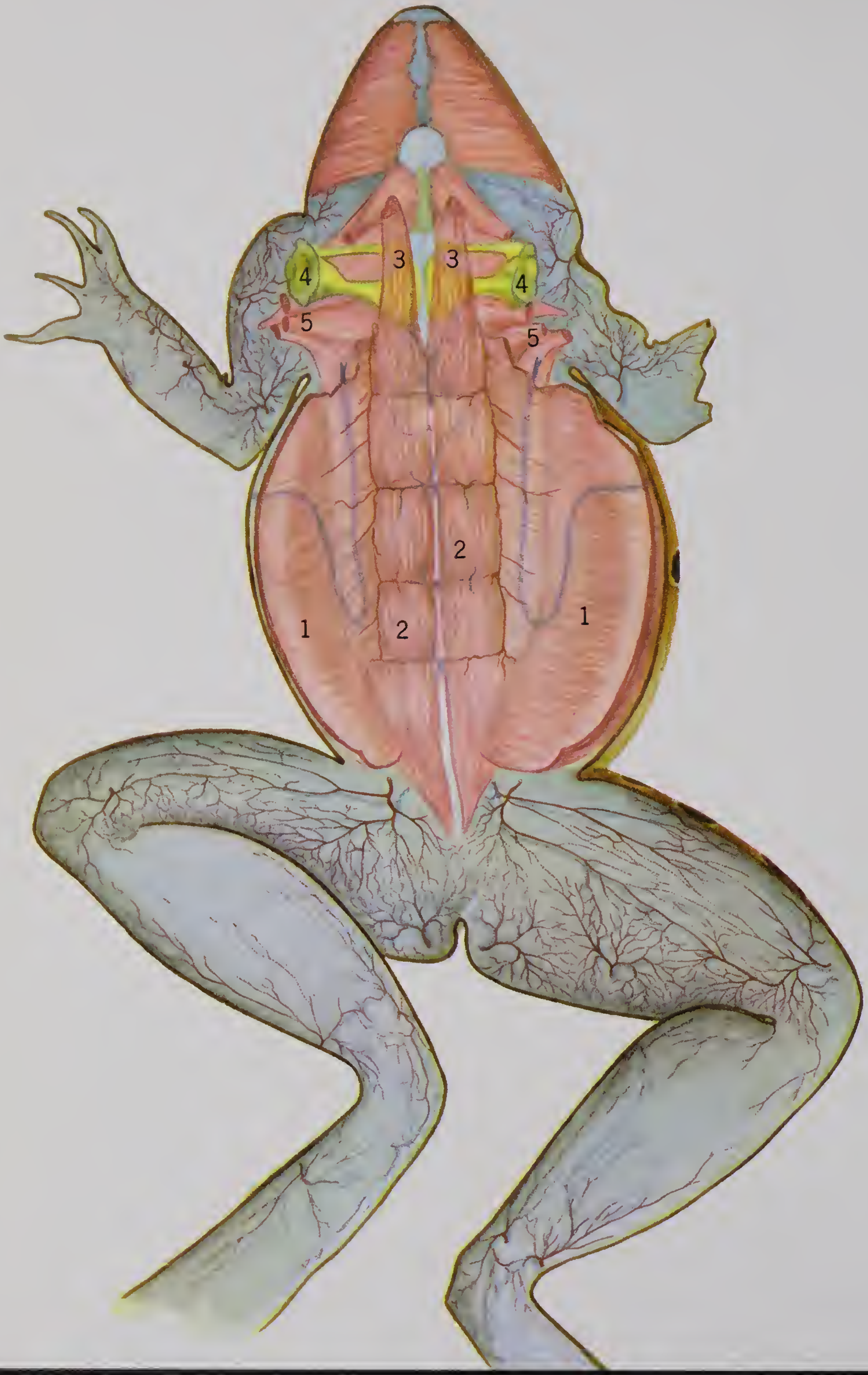
APPLYING PRINCIPLES AND CONCEPTS

1. Explain why biologists believe that legs were developed to find water rather than to leave it.
2. Although the amphibians became terrestrial, discuss why they were never successful on land.
3. Discuss the problems in the life of a toad that result from its "in-between" existence.
4. In what respect is the direct fertilization of the frog's eggs more efficient than spawning in fishes?
5. Explain how the frog shows a relationship to the fish in its early development.
6. In what ways are the heart and circulatory system more highly developed in the frog than in fishes?

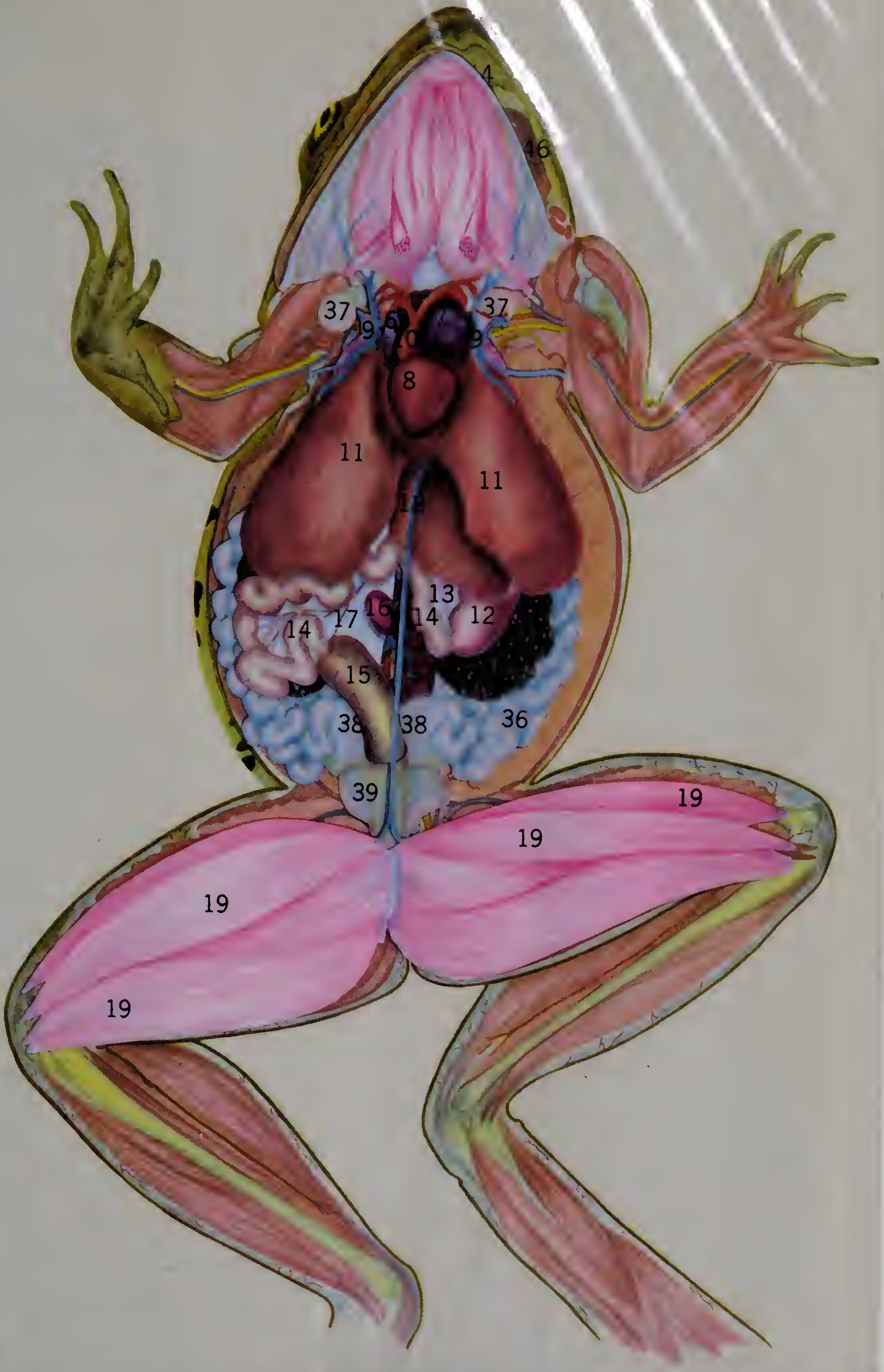
Key to the Structures of the Frog

1. Transverse abdominal muscles
2. Vertical abdominal muscles
3. Muscles to floor of mouth
4. Sockets for attachment of arms
5. Shoulder muscles
6. Right atrium (auricle) of heart
7. Left atrium of heart
8. Ventricle of heart
9. Great veins to right atrium (auricle)
10. Great artery from heart (conus arteriosus)
11. Liver
12. Stomach
13. Pancreas
14. Small intestine
15. Large intestine (colon)
16. Spleen
17. Mesentery
18. Abdominal vein
19. Leg muscles
20. Tongue
21. Glottis opening
22. Trachea
23. Lungs
24. Sinus venosus
25. Pulmonary veins
26. Gall bladder
27. Bile duct
28. Hepatic portal vein
29. Sockets for attachment of legs
30. Gullet
31. Vein from kidneys (posterior vena cava)
32. Kidneys
33. Dorsal aorta
34. Fat bodies
35. Ovaries
36. Oviducts
37. Openings of oviducts
38. Egg sac (uterus)
39. Urinary bladder
40. Cloaca
41. Lining of mouth
42. Veins from legs to kidneys (renal portal vein)
43. Ureters
44. Internal nostril openings
45. Vomerine teeth
46. Teeth of the upper jaw
47. Openings of Eustachian tubes
48. Eye sockets
49. Brain
50. Spinal cord
51. Spinal nerves

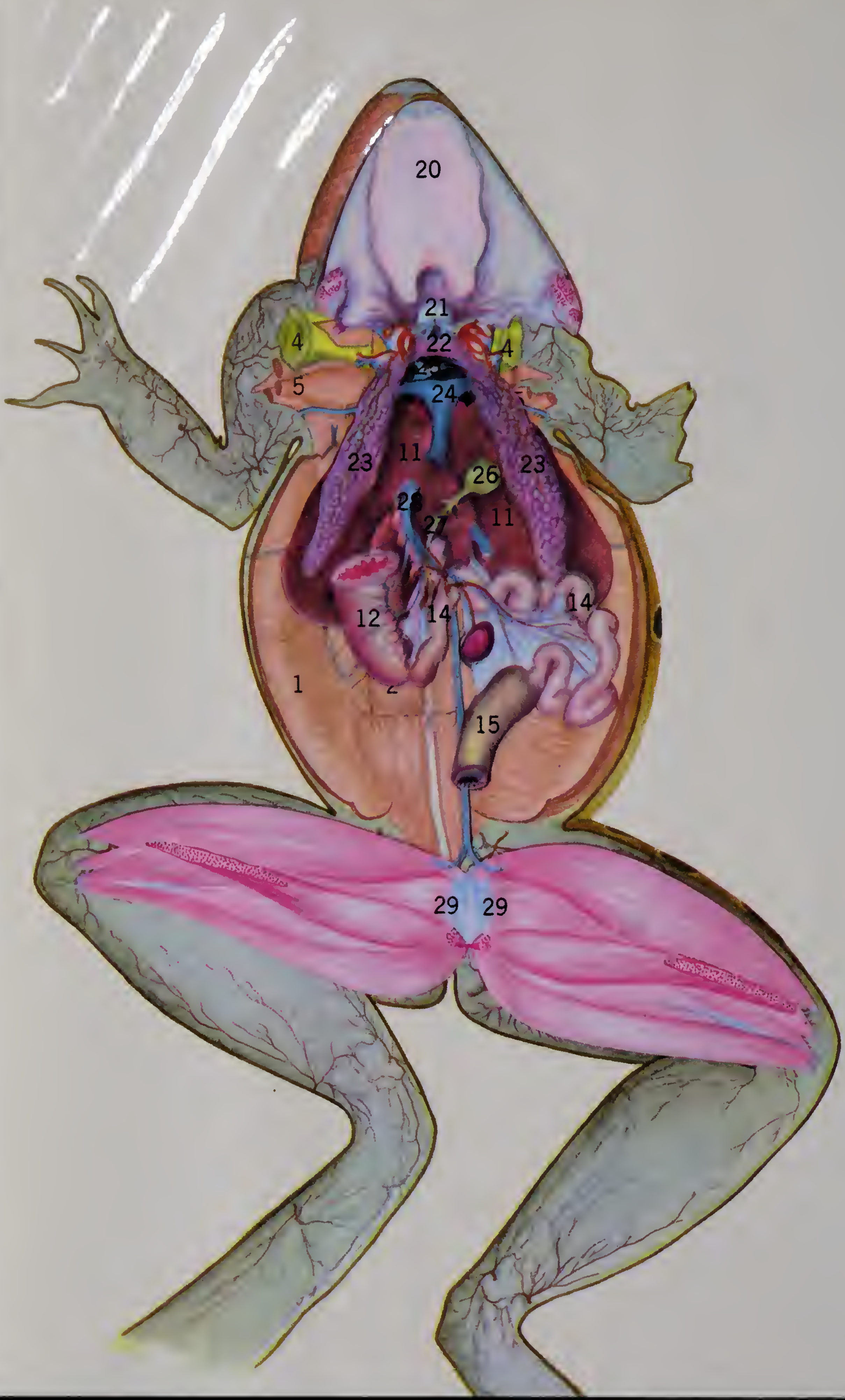




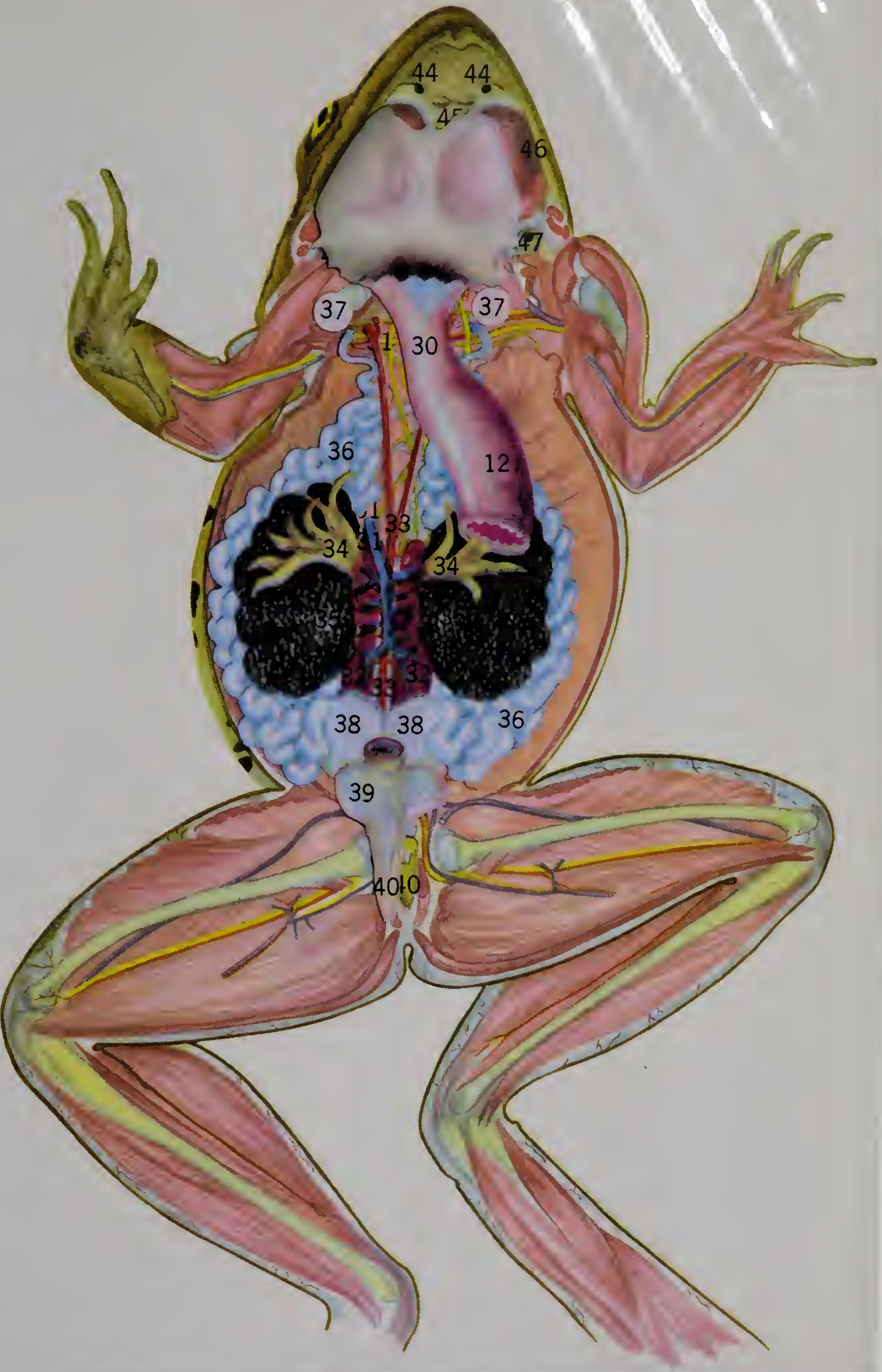
II LAYER OF SKIN AND MUSCLES REMOVED FROM VENTRAL SIDE OF THE FROG. Looking at this layer from the inside, you see the many blood vessels of the skin. Notice the transverse abdominal muscles (1), and the vertical abdominal muscles (2). The large muscles (3) which aid in mouth breathing have been cut. The ends which attach to the floor of the mouth show in the next drawing. In the shoulder are the bones which form the socket (4) for the attachment of the arms and the cut ends of some of the shoulder muscles (5).



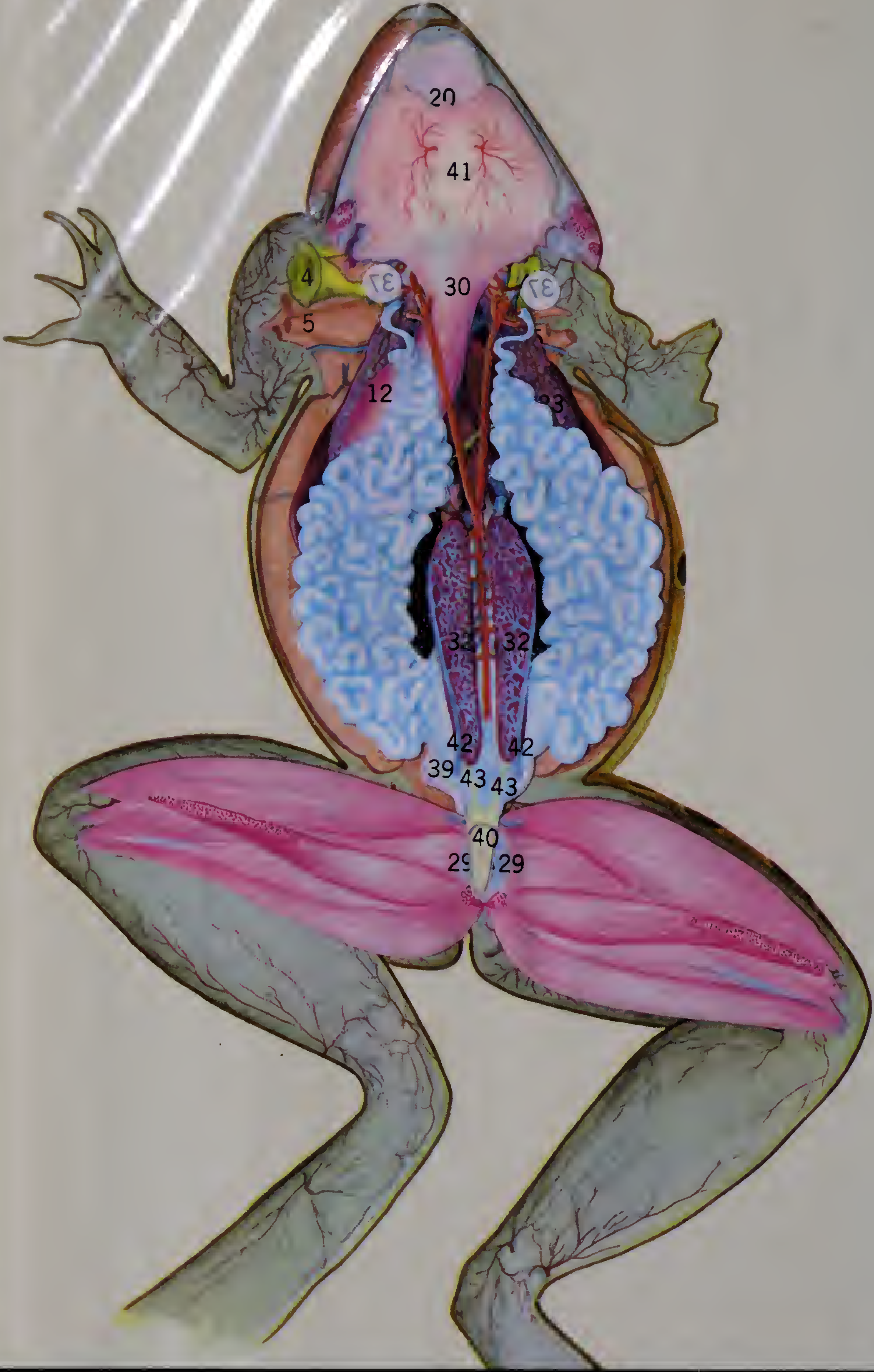
III CUTAWAY VIEW SHOWING THE FROG LYING ON ITS BACK WITH FRONT BODY WALL REMOVED. The heart is composed of a right auricle (6), a left auricle (7), and a ventricle (8). Great veins (9) carry blood into the heart and a great artery (10) carries blood away from the heart. The liver (11) covers most of the stomach (12) and pancreas (13). The small intestine (14) leads from the lower end of the stomach to the large intestine (15). The spleen (16) lies in the thin layers of mesentery (17) which fasten the abdominal organs to the body wall. The large abdominal vein (18) carries blood from the legs to the liver. Powerful leg muscles (19) enable the animal to swim and jump.



IV CUTAWAY VIEW SHOWING THE FLOOR OF THE MOUTH AND ORGANS VIEWED FROM THE BACK. The fleshy tongue (**20**) nearly covers the floor of the mouth. Vocal cords lie just inside of the slitlike glottis opening (**21**). A very short trachea (**22**) leads to the lungs (**23**). On the back of the heart are the large veins which combine in a thin-walled sac, the sinus venosus (**24**) before entering the right auricle. Above this, the pulmonary veins (**25**) enter the left auricle. The gall bladder (**26**) receives bile from the liver (**11**) and passes it to the small intestine (**14**) through the bile duct (**27**). The hepatic-portal vein (**28**) carries blood from the small intestine to the liver. The stomach (**12**) and large intestine (**15**) are cut open in this view. Sockets (**29**) which hold the leg bones are visible in the pelvic region.

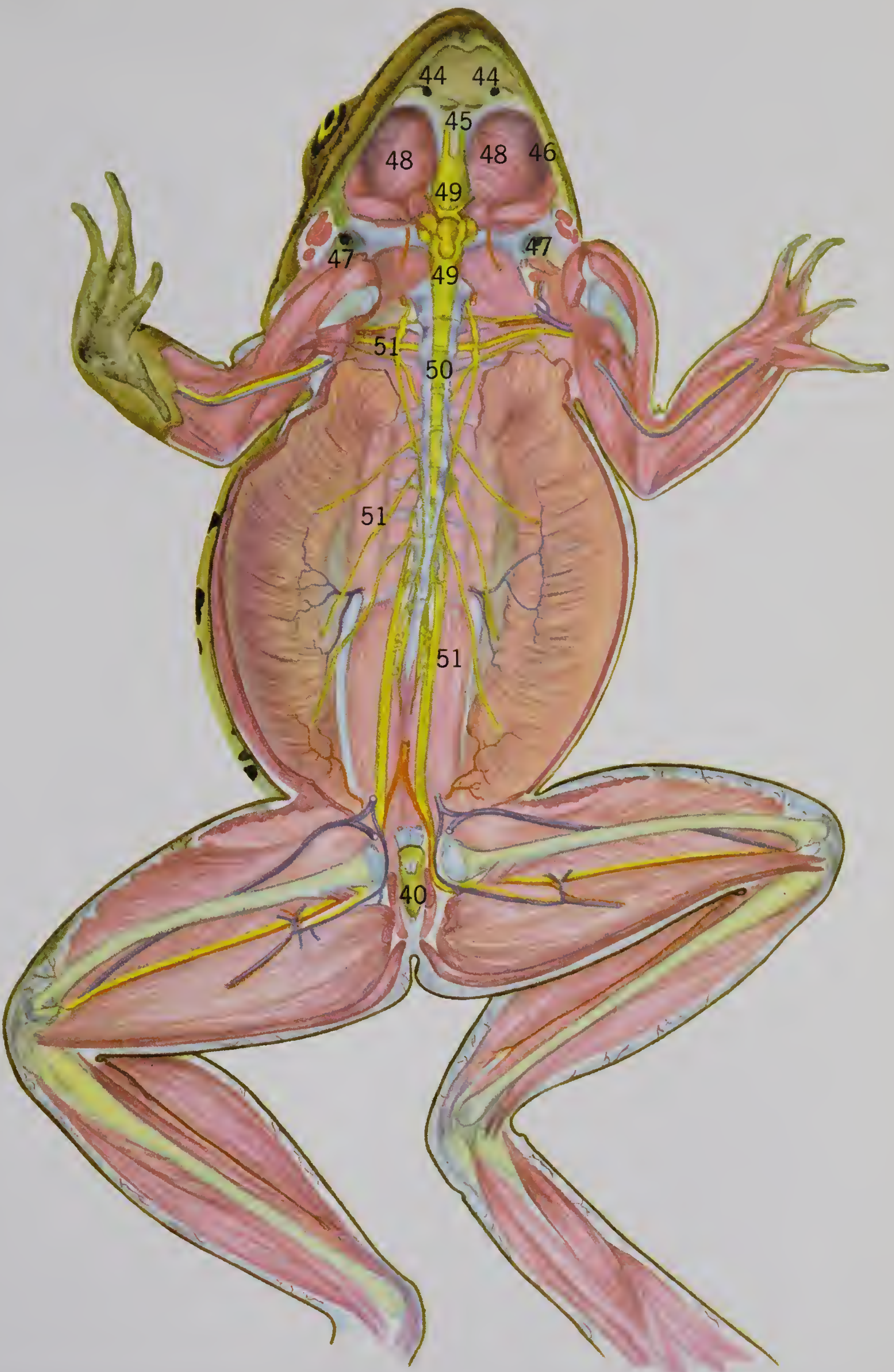


V **CUTAWAY VIEW SHOWING THE ROOF OF THE MOUTH AND DEEPER ORGANS AS SEEN FROM THE FRONT.** The short, wide gullet (30) opens at the back of the mouth and leads to the stomach (12). A large vein (31) collects blood from the kidneys (32). The dorsal aorta (33) carries blood to the internal organs and lower parts of the body. Fat bodies (34) attach near the top of the ovaries (35). Eggs break out of the ovaries and enter the oviducts (36) at openings (37) near the base of the lungs. Until they are laid, eggs are stored in sacs (38) at the lower end of the oviducts. The urinary bladder (39) attaches to the cloaca (40).

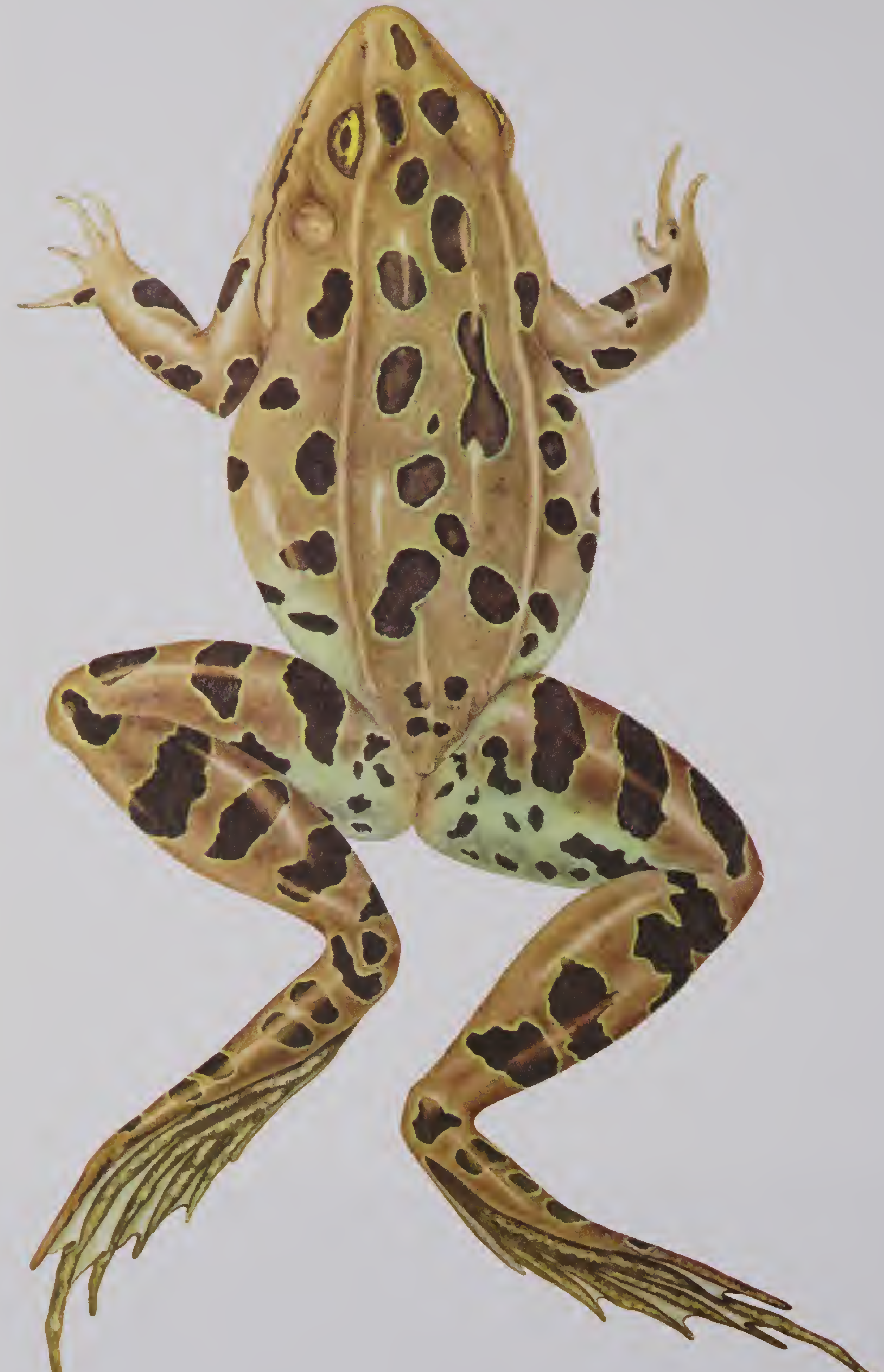


TRANS-VISION® MILPRINT, INC.
MILWAUKEE, WISCONSIN

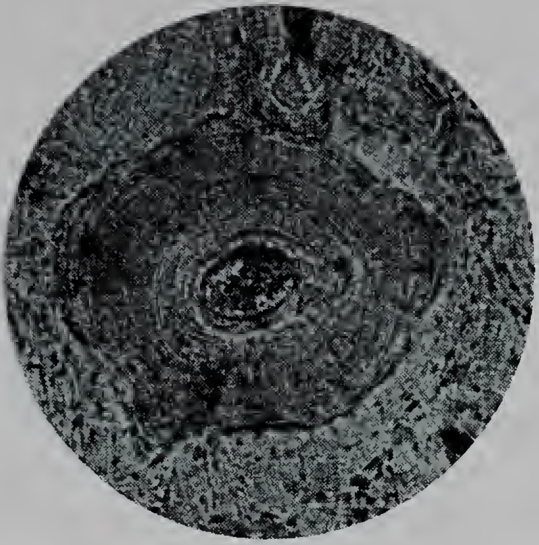
VI CUTAWAY VIEW SHOWING DEEPER ORGANS AS SEEN FROM THE BACK. The lining of the mouth (**41**) shows its rich blood supply. You see the gullet (**30**) and stomach (**12**) from the dorsal side. Veins (**42**) carry blood from the legs to the kidneys (**32**). Near these are the ureters (**43**) which carry urine to the cloaca (**40**) which is cut open in the drawing. Urine passes from the cloaca into the urinary bladder (**39**), where it is stored.



VII CUTAWAY VIEW SHOWING BACK BODY WALL AS SEEN FROM THE FRONT WITH ORGANS AND SOME OF THE LARGE LEG MUSCLES REMOVED. Internal nostril openings (**44**), vomerine teeth (**45**), teeth of the upper jaw (**46**), Eustachian tube opening (**47**) and eye sockets (**48**) can be seen in this view of the head. The cranium and spine are shown as though they were transparent to show the brain (**49**) and spinal cord (**50**). Spinal nerves (**51**) emerge from each side of the spinal cord. Dissection of the lower leg muscles exposes bones and joints, blood vessels, and the dorsal wall of the cloaca (**40**) with ureter and oviduct openings.



CHAPTER 36



THE REPTILES

The rise of the reptiles. Amphibians were never successful land dwellers. Most of the adults had to remain near water. Both eggs and young required either a water environment or at least moist surroundings. Biologists believe that millions of years must have elapsed before a vertebrate evolved that could live entirely on land. Two significant advances probably made a completely terrestrial life possible. The first and perhaps most important was the development of an egg with a shell. The shelled egg prevented drying, and freed animals from the necessity of returning to the water for laying eggs. The eggs of modern reptiles all have shells, and the developing embryo within the egg is surrounded by a thin membrane, the *amnion*. The amnion is filled with a watery fluid, providing the embryo with a liquid environment even though the egg is laid on dry land. A large yolk provides sufficient nourishment for the reptile to develop to a more advanced stage before it is hatched. This eliminates the tadpole stage and metamorphosis. The development of the ***amniote egg*** is one of the most important adaptations of the class ***Reptilia.*** Internal fertilization accompanied the development of a shelled egg. Otherwise a sperm would be unable to penetrate the shell to fertilize the egg nucleus. A second factor that contributed to the success of animals on land was the development of a more suitable body covering. The skin of reptiles resists loss of water by evaporation so effectively that they are even found in deserts where the temperature is high and the humidity is very low.

Unfortunately it is impossible for paleontologists to determine exactly when the transition from amphibian to reptile took place. Fossil remains are generally limited to hard parts such as bones and teeth. But some of the important differences between the two groups are in the soft tissues, which do not become fossilized. It is therefore often impossible to be sure whether a fossil is an amphibian or a reptile. Fossils of true reptiles have been found in the late Carboniferous period (Fig. 13–1, page 183). But there is some evidence that there were animals with reptilian characteristics before this period. Certainly the first reptiles had little advantage over their amphibian relatives. They must have been nearly as restricted to the water environment. There is little doubt that the transition to land occurred slowly. Fossil evidence indicates that not until late in the Carboniferous period did reptiles become truly terrestrial.

The first reptiles were small and were minor competitors of other animals living in the Carboniferous swamps. But during the Permian period, changes in land formations created a variety of environments. Animals equipped to live in these new habitats were assured of life with little competition. Variations in size, shape, and behavior seem to have allowed the reptiles to live in the different environments — a good example of adaptive radiation. From an unimportant beginning in the Carboniferous period, reptiles became the most important animals on the land, in the air, and perhaps even in the sea during the Mesozoic Era — the age of reptiles.

The age of dinosaurs. Eggs and footprints preserved in rock and fossilized bones are all that remain of the age when dinosaurs roamed the earth. Yet, with this evidence, gathered in many parts of the world, and considerable imagination, the paleontologist has been able to piece together a vivid picture of the earth during the time when dinosaurs dominated animal life.

Dinosaur is an appropriate name for these ancient reptiles, for it means "terrible lizards." Many of the dinosaurs were no larger than our larger lizards today. But some of them were giant beasts that would dwarf an elephant. These are the best known dinosaurs.

The largest of the dinosaurs was the thunder lizard, or *Brontosaurus*. This giant measured 75 feet in length, about 15 feet in height, and weighed 30 tons or more. It lived in shallow lakes and marshes and fed on water plants. Its enormously long neck was balanced by an equally long and heavy tail. The plated lizard, while smaller than the thunder lizard, was one of the heaviest-armored of the dinosaurs. *Stegosaurus* (steg-oh-*sor*-us), as this 30-foot monster has been named, had a double row of plates projecting two feet from its back. Pairs of spines near the end of the tail served as deadly weapons with which to lash out at an enemy. *Stegosaurus* had a ridiculously small head with a cranial cavity no larger than that of a small dog. An auxiliary "brain" 20 times larger than the true brain consisted of a mass of nerve tissue formed by the spinal cord in the hip region.

36-1 The herbivorous dinosaur, *Stegosaurus,* though it looked dangerous, had a small brain in proportion to the size of its body and was unable to protect itself against enemies. Here it is being attacked by a much smaller but carnivorous dinosaur with sharp teeth. (Ewing Galloway)

This second "brain" is thought to have controlled the seven-foot hind legs and ponderous tail of the animal.

The king of dinosaurs was the ferocious tyrant lizard, or *Tyrannosaurus* (ty-ran-oh-*sor*-us), which is probably the most terrible creature ever to roam the earth. It walked erect on its powerful hind legs and balanced its heavy body with its long tail, much in the manner of a kangaroo. Its front legs were short but powerful, and its long claws could tear most prey into shreds. This giant flesh-eating reptile was nearly 50 feet in length and towered 20 feet in height. Its powerful jaws were rimmed with double-edged teeth three to six inches long that could rip the hide of even an armored victim.

Classification and characteristics of living reptiles. Some 6,000 species of reptiles exist in the world today as remnants of the Age of Reptiles. They still exceed the number of species of mammals, but are surpassed by the species of birds or fishes. About 275 reptile species are found in the United States. Some are much like their ancestors; others have become greatly modified. The geographic distribution of the reptiles indicates that the modern reptiles originated in the tropics, but they have migrated to some of the colder parts of the earth. Only the icy regions, the tops of mountains, and the ocean depths are completely without reptiles. Of the 16 orders of reptiles that once existed, only the four orders that include turtles, crocodiles, lizards, and snakes are represented today (see table below). One of these remaining orders is so near extinction that it is represented today by a single species.

Reptiles show the following characteristics:

1. Body usually covered with scales.
2. Skin dry, not moist and slimy.
3. Feet, if present, have claws on the toes.
4. Eggs internally fertilized and, if laid, have a protective shell. Certain species retain the eggs within the body and bring forth the young alive.
5. No metamorphosis.
6. Gills never present, as both young and adults breathe with lungs.
7. Body temperature changes with environment (cold-blooded).

Sphenodon, a relic of a bygone age. One of the rarest animals on the earth today is the sole surviving species of the order Rhynchocephalia. This ancient reptile, even older than the dinosaurs, is the *Sphenodon punctatus* (*sfee*-noh-don punk-*tay*-tus), or tuatara (too-a-*tahr*-a). Its relatives disappeared early in the Mesozoic Era, probably because they could not compete with more adaptable lizards. This strange survivor of the age of reptiles miraculously escaped ex-

ORDERS OF LIVING REPTILES

Name of Order	*Representatives*
Testudinata or Chelonia	Turtles and tortoises
Rhynchocephalia	*Sphenodon* (tuatara)
Squamata	Lizards and snakes
Crocodilia	Alligators, crocodiles, gavials, and caimans

tinction through the ages in far off New Zealand and neighboring islands. The tuatara probably survived there because of a total absence of mammals. Once the English settlers had introduced rats, wild pigs, cats, and weasels in New Zealand, the tuatara became extinct on the mainland. Today the last surviving tuataras are found on a few small islands in the Bay of Plenty and in Cook Strait off the coast of New Zealand, where they are protected by the government. It is a challenge to biologists to preserve the remaining tuataras.

Because of a very limited evolution in the Rhynchocephalia, today's tuataras retain many primitive features. Since animals similar to the tuatara lived 170 million years ago, it is clear that the rate of evolution in this order must have been one of the slowest in the vertebrate groups. The tuatara reaches a length of about two feet and resembles a large lizard (Fig. 36–2). Its skin is dark olive, marked with numerous light colored dots. Its eyes resemble those of a cat. The most unusual characteristic of the tuatara is a ***parietal eye*** (pa-*ry*-et-l) in the top of its head. While not a functioning sense organ, this strange third eye has the remains of a retina and other eye structures. The tuatara hides in a burrow during the day, coming out at night to feed on insects, worms, and other small animals. The eggs are buried in a shallow depression in the ground, where they remain almost a year before hatching. The female tuatara usually lays 12 to 14 eggs. The fact that the tuatara lives well in captivity may make it possible to preserve this rare species in the reptile collections of the world.

Snakes, the most widespread reptiles. Snakes are relative newcomers. As with the early ancestors of the reptiles, there is no fossil record of snakes. But there is little doubt that they evolved from typical reptiles. In fact the boas and pythons still have the remains of hind limbs, indicating that they descended from animals with legs. Snakes evolved rapidly during the Tertiary period, at the same time rodents and other small mammals were developing. Snakes are not only the most numerous reptiles today, they are also the most widely distributed. Snakes are found in water, on the high seas, among rocks, under ground, and in trees. They are most abundant in the tropical regions. Their numbers reduce in cooler climates to 126 species in the United States and only 22 species in Canada.

36-2 *Sphenodon punctatus,* the tuatara of islands near New Zealand, is the only surviving species of a once flourishing order. (American Museum of Natural History)

Of the more than 2,000 species of snakes in the world, a relatively small number are poisonous. The harm caused by these dangerous snakes is far outweighed by the valuable service all snakes render in destroying large numbers of insects and destructive rodents.

Body structure of a snake. If you examine the elongated body of a snake closely, you can distinguish the head, the trunk, which contains the body cavity, and a tail, which extends beyond the anal opening. As in all reptiles, the snake's body is covered with scales. Those on the back and sides of the body are small and oval, thus allowing great flexibility. The heads of many snakes, including our nonpoisonous species, are covered with plates. The North American pit vipers, including the rattlesnake, have scale-covered heads. The scales on the lower side of the body form broad plates, known as *scutes* (skyoots).

Each season during the process of molting, snakes shed the outer layer of scales several times. As this thin layer loosens all over the body, the snake usually hooks a loose portion to a sharp object such as a twig and works its way out of it. After molting, the newly exposed scale surfaces are bright and shiny.

Structures of the head. The snake's mouth is large and is provided with a double row of teeth on each side of the upper jaws and a single row in the lower jaw. The numerous conical teeth slant backward toward the throat. None of the teeth serve for chewing but are necessary to hold the prey, which is swallowed whole.

The sense of smell in snakes is very acute. Olfactory nerve endings lie in the nasal cavities, which open as paired nostrils near the front of the head. The sense of smell is made more acute with the aid of the curious forked tongue, which is thrust from a sheath in the floor of the mouth close to the front through a small opening that is left when the jaws are closed. The tongue receives dust and other odor-bearing particles from the air and transfers them to tiny pits close to the front of the roof of the mouth. These *Jacobson's organs*, as they are called, contain nerve endings that are highly sensitive to odors.

The snake's eyes have no lids and in this respect are different from those of other reptiles. A transparent scale covers the eye. This becomes cloudy just before molting and causes temporary difficulty with vision. The eyeball can be turned in its orbit. Movement of the lens focuses the eye sharply on objects, especially at close range. Many snakes have round pupils. Biologists have discovered that these snakes are most active in daylight. Others have elliptical pupils, similar to those of a cat. These snakes are most active at night.

The ears are embedded in the skull and have no external openings. Thus, the snake cannot hear vibrations transmitted by the air. Instead the skull bones transmit vibrations resulting from jarring to the highly sensitive ear mechanisms.

Feeding habits of snakes. All snakes feed on living animal prey. No vegetarian snakes are known to exist. We classify snakes into three groups, based on feeding habits.

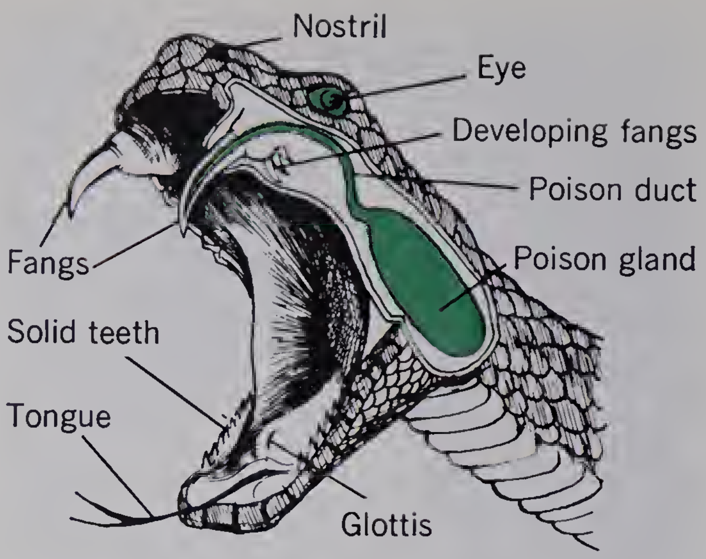
Many snakes, including most of our nonpoisonous species, merely seize a prey in the mouth and *swallow it alive*. Most of these snakes feed on insects, frogs, toads, lizards, fishes, and other small animals.

The python, boa, king snake, bull snake, and other large-bodied snakes make use of a more specialized method of food-getting. These snakes seize the prey, usually by the head, wrap coils around it with lightning speed, and kill it quickly by *constriction* (Fig. 36–3). The powerful coils squeeze the victim with such force that its chest is compressed and breathing is stopped. In addition the pressure cuts off the victim's circulation and stops the heart. The shock kills the prey, often without breaking a bone. If, after the first constriction, the snake feels a pulse in its victim, it will squeeze again. Swallowing starts immediately after the prey is killed. Biologists have found that warm-blooded animals are killed much more quickly by constriction than cold-blooded prey.

A relatively small number of snakes *poison the prey* before swallowing it. Poisonous snakes secrete ***venom*** in modified salivary glands at the sides of the head. When a poisonous snake strikes, paired fangs are thrust into the victim. Venom flows from the poison glands through ducts that enter the fangs (Fig. 36–4). The hollow fangs, through which venom flows into the victim, are like hypodermic needles. The amount of venom injected varies with the size and species of snake. However, smaller species, as well as the young of larger species, have more concentrated venom. Thus their bites may be just as dangerous as those of larger poisonous snakes.

Adaptations for swallowing. Snakes are infrequent feeders. They may go for weeks or, under some conditions, as long as a year without food. However, when they do eat, it is amazing to watch a snake swallow a prey four or five times larger than its own body. This feat is made possible by several modifications of the jaws. The lower jaws are not joined directly to the skull but are fastened to a separate ***quadrate bone***, which acts as a hinge and allows the jaw to drop downward and forward (Fig. 36–5). The two halves of the lower jaw are fastened at the front by an ***elastic ligament***, which permits each half to operate independently of the other. The numerous slanting teeth hold the prey firmly during the swallowing process.

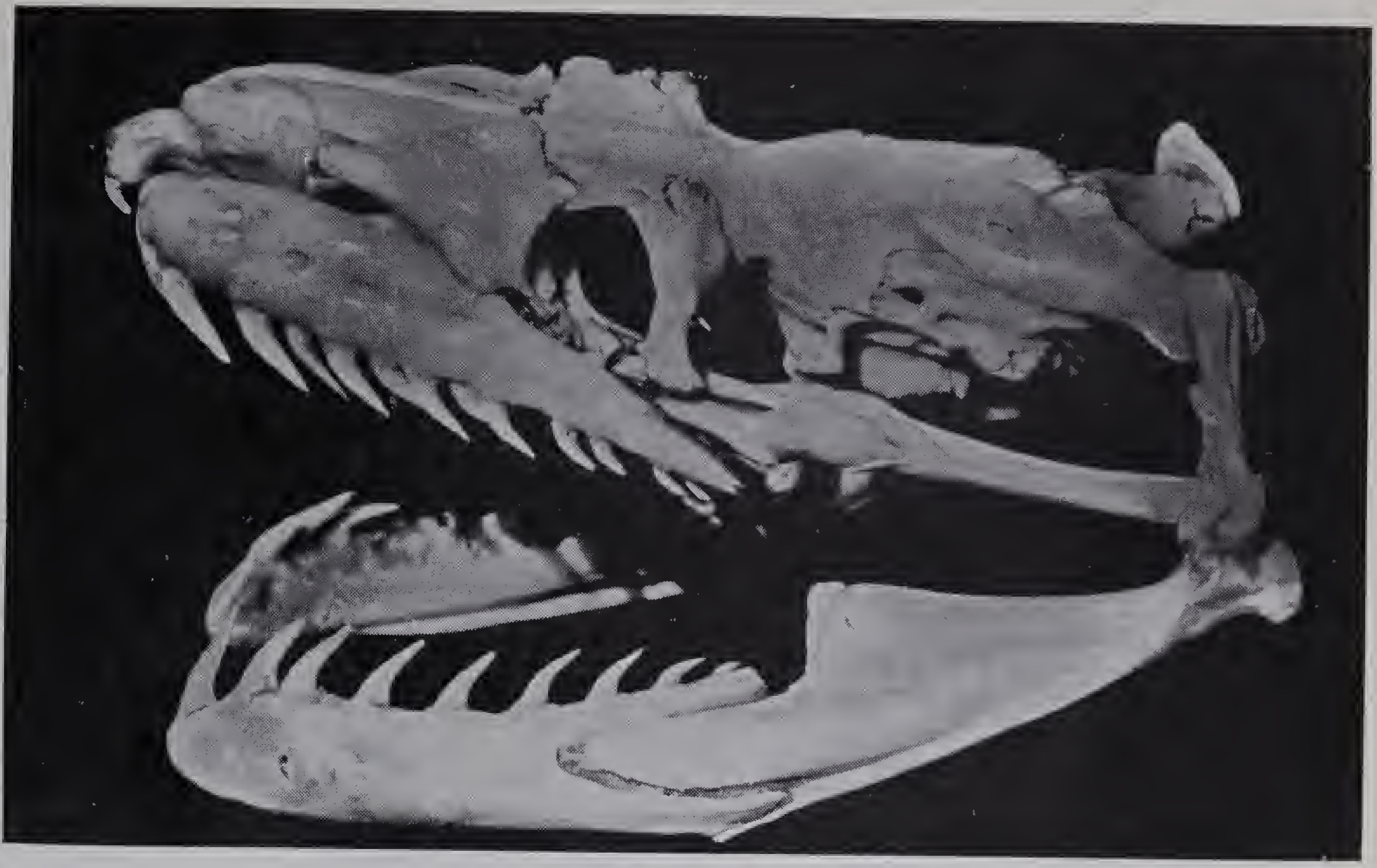
36-3 Pythons obtain their food by curling their powerful bodies around their victim and crushing it. (Lilo Hess)



36-4 The rattlesnake poisons its prey with venom before swallowing it whole. The head structures are modified for poisoning and swallowing.

During swallowing, one side of the lower jaw may pull the prey into the mouth while the other side is thrust forward for a new grip. By this see-saw action, the prey is pulled down the throat much as you might pull in a rope hand over hand. The snake literally crawls forward around its prey.

The process of swallowing takes so long that special adaptations are necessary to permit the snake to breathe while a large prey is in its mouth and throat. The trachea extends along the



36-5 What adaptations for swallowing large prey are shown in this photograph of a snake's skull? (American Museum of Natural History)

floor to a glottis opening near the front rim of the lower jaw.

Locomotion in snakes. Several methods of locomotion are found among snakes. The most common method is ***lateral undulatory movement.*** The body winds from side to side, forming broad curves. The snake pushes against irregularities, which give it a grip in moving forward. The entire body follows along the same track in this type of movement, used when the snake is crawling rapidly. This type of movement is also used by water snakes in swimming.

A snake may crawl slowly in a straight line by ***caterpillar movement.*** Scutes are pushed forward in several sections of the body. The posterior edge of each scute grips the ground while the body is pulled forward by waves of muscular contraction.

A third method of movement, known as ***side winding,*** is used by snakes of the sandy desert regions. Here, the body is twisted into S-shaped loops and is raised from the ground except for two or three points of contact. The sidewinder "walks" across the sand on these loops.

You may be relieved to learn that most snakes travel at a speed of less than one mile per hour. The fastest ones cannot exceed three miles per hour. You can walk at this speed with ease, and you can run a short distance at a speed of from 10 to 20 miles per hour. Thus you need have no fear of being run down by a snake!

Internal organs of a snake. Over 300 pairs of ribs attach to the vertebrae of the spine in a snake. These ribs are set in muscle and are flexible, permitting movement and allowing large prey to pass through the body. The gullet and stomach are highly elastic and the digestive secretions are powerful, in order to accommodate whole prey which snakes swallow for food.

36-6 The garter snake is ovoviviparous, bringing forth its young alive. (American Museum of Natural History)

The right lung is well developed. The left lung is stunted or absent entirely. Flexible ribs permit expansion of the body wall in breathing. The large heart has a ***septum*** partially dividing the ventricle into the two chambers.

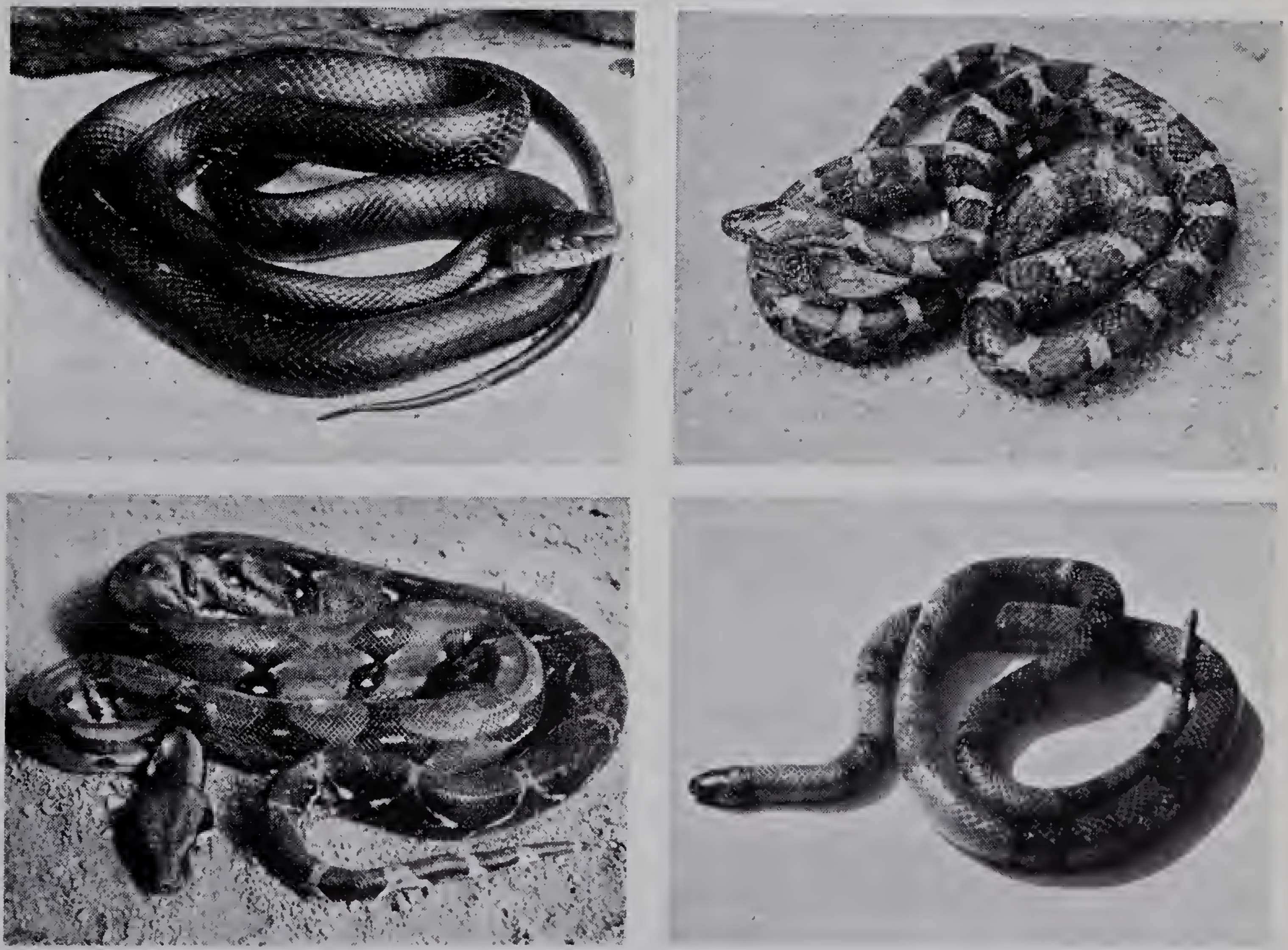
Since the snake is cold-blooded, the rate of oxidation is much lower than that of a warm-blooded animal; and much less heat is generated in their bodies. Under resting conditions, a snake is often slightly colder than its surroundings. Also the heat they do produce is quickly lost since they have no coat of fur or feathers. The reptile is at a disadvantage in being cold-blooded and living on land. In cold regions it cannot be active during the winter. During hot weather, it must seek shelter through the day since it has no method of cooling the body below the level of whatever the outdoor temperature happens to be.

Reproduction in snakes. The majority of snakes lay eggs that resemble those of the other reptiles. Each egg, enclosed in a tough white shell, contains stored food to nourish the young snake during its development. The eggs receive no care from the female after being laid and no incubation except the warmth of the sun. Egg-laying snakes are called ***oviparous*** (oh-*vip*-uh-rus); they include the black snake and blue racer.

A smaller group of snakes, including the garter snake and the copperhead, bring forth their young alive, usually in the late summer (Fig. 36–6). The eggs are not laid but remain in the uterus where they develop into young snakes. During development, there is no nourishment provided from the mother's body as in the mammals. Snakes that bring forth the young alive are classed as ***ovoviviparous*** (oh-voh-vy-*vip*-uh-rus), as distinguished from the higher animals, which are called ***viviparous*** (vy-*vip*-uh-rus) and which nourish their young during development.

Nonpoisonous snakes. The snakes may be divided into two distinct groups on the basis of whether they produce toxins or not. You are probably familiar with the harmless *garter snake, black snake,* and *racers.* We should be interested in protecting these snakes as they destroy insects, rats and other rodents. The *king snake* is one of the most valuable snakes, as it eats other snakes and rodents. The *constrictors* of South America, Africa, and Asia, are also nonpoisonous snakes.

Poisonous snakes. The poisonous snakes are grouped in four families, all of which have developed specialized teeth or fangs for the injection of poison. The *cobras* are almost entirely limited to the tropics of Africa and Asia. Some of the members of the cobra family are deadly to man. The king cobra of Siam is the largest of all poisonous snakes. Some species of cobra spit venom at their enemies. The fine spray of poison can travel several feet with surprising accuracy and can cause temporary or permanent blindness if it enters the eye. The *coral snakes* of America are related to the cobras. They are relatively small, with strikingly beautiful coloration. Their venom is very potent, but they cause few fatalities because they have very short fangs which



36-7 Nonpoisonous snakes include the black snake and milk snake (top left and right), and the boa constrictor and king snake (bottom left and right). (American Museum of Natural History)

36-8 The cobra is one of the most deadly poisonous of all snakes. (American Museum of Natural History)

are unable to penetrate shoe leather or heavy clothing.

The *sea snakes* are related to the cobra but are usually placed in another family. Although the sea snakes are very poisonous, they seldom harm man as they are strictly marine creatures. Fishermen, however, fear these snakes, for on rare occasions a specimen is hauled aboard a fishing vessel. Sea snakes inhabit the shallow waters of the East Indies, and one species is frequently seen off the west coast of tropical South America, Central America, and Mexico.

The third group of venomous snakes is the *vipers*. This family includes all the poisonous snakes of Europe, Africa, and Asia that do not belong to the cobra family. The most abundant viper is the common European viper, which is known in England as the adder. The largest number of viper species occurs in Africa. Vipers have large hollow fang teeth that are held in an erect position when the mouth is open but are folded flat when the mouth is closed.

The fourth family, the *pit vipers*, is distinguished from the true vipers by the presence of a highly specialized organ that is sensitive to temperature. These pits are located on either side of the head, in front of the eyes. Biologists have determined that the pit senses infrared rays. This enables the pit vipers to strike accurately at any prey that produces heat. Since most of the prey of the pit vipers are warm-blooded animals, this adaptation gives them a strong advantage in securing food. Although some pit vipers exist in southern Asia, most species are found in North and South America. The best known are the *copperhead*, the *cottonmouth moccasin* (both of North America), the *fer-de-lance* and *bushmaster* of South America, and the numerous *rattlesnakes* of both continents.

Rattlesnakes are the most widely distributed poisonous snakes in the world. Their range extends from northern Argentina to southern Canada. Of the 19 or more kinds of rattlesnakes found in the United States, at least 12 species occur in the southwest. These include the prairie rattlesnake, western diamond rattlesnake, and horned rattlesnake, or sidewinder, of the desert regions. The range of the timber rattlesnake includes most of the eastern United States. The largest of North American rattlesnakes, the diamondback, lives in marshy areas of the Southeast. Six- to eight-foot specimens have been taken in southern swamps.

Rattlesnakes have a series of dry segments, or rattles, on the end of the tail. When the snake is disturbed, it vibrates these rapidly, causing a whirring sound, which explains why few people are bitten by rattlesnakes even though they are widely distributed. Usually you can step away from danger when you hear and recognize a rattlesnake's warning.

The head of a rattlesnake is large and triangular. The jaws are puffy, because of the presence of poison glands (Fig. 36–4). Near the front of the upper jaw is a pair of large, hollow teeth, or fangs. The fangs are fastened to a bone that is hinged on the upper jaw so that when the snake's mouth is closed, the fangs fold upward against the roof of the mouth. They are pulled down by muscles when the snake opens its mouth to strike. The rattlesnake can strike fiercely a distance of one third the length of its body or more. The fangs are driven deep into the flesh of its victim, and poison flows from the glands, through the fangs, and into the wound. Both the length of the fangs and the large amount of poison injected make the rattlesnake bite extremely dangerous, especially when the fangs happen to go into a vein.

Rattlesnakes, especially the diamondback, have several economic uses. The skin is used for purses, belts, and other articles. In many regions the flesh is eaten. The venom is taken from captive specimens and is used for making ***antivenin***, a biological product used in treating pit viper bites.

Two types of snake venom. The toxic portion of snake venom is made up of various complex protein substances. One type of poison, called ***neurotoxin***, affects the parts of the nervous system that control breathing and heart action. The second type, called ***hemotoxin***, destroys red blood cells and breaks down the walls of small blood vessels. All poisonous snakes contain both types, but the proportion varies with the species. The venom of cobras, coral snakes, and sea snakes is usually mostly neurotoxic. Vipers and pit vipers produce venom that tends to be mostly hemotoxic.

The danger from snakebite varies with the amount of venom injected; the concentration of toxins in the venom; the part of the body receiving the bite; and whether the venom enters the main circulatory system rapidly (through a blood vessel) or slowly (through a muscle or fatty tissue). In the tropics, snakebite is a serious problem. As many as 40,000 people may die annually from snakebite. Cobra bites kill many people in India. In the temperate regions, few people die from snakebite. Still, the bite of any poisonous snake should be regarded with the greatest possible seriousness and treated at once.

Treatment of snakebites. We now have efficient methods of treating the bites of pit vipers. Treatment must be started immediately since much of its success depends on preventing the spread of venom through the blood stream. The following steps should be taken at once:

1. Keep the victim quiet and reassured, to prevent speeding up of heart action.
2. Put a constricting band, made from a piece of cloth, a cord, or a necktie, between the wound and the heart. Tighten it firmly, but not enough to cut off the circulation completely. The tourniquet should be loosened by a doctor.
3. If ice is available, pack the area around the wound in it. This method of treatment is now regarded as superior to binding with a tourniquet as outlined in step 2.

The lizards. Of the more than 2,500 species of lizards, only a few are native to the United States. Lizards are chiefly tropical animals, although a few species extend into the colder temperate regions. Many lizards are strange and beautiful. Because of their resemblance to dragons and dinosaurs, they are feared by many people. But most of them are shy, harmless creatures. Of all the fierce-looking animals included in this suborder, only two are poisonous. The lizards have evolved from the Mesozoic Era to the present time. Of all the modern reptiles, the lizards have developed the greatest number of adaptations for different environments.

The *iguanas* (i-*gwah*-naz) are considered primitive lizards. They tend to possess the typical lizard appearance and proportions; few have evolved any advanced characteristics. Included in this family is the so-called horned toad, which has a series of horny spines on its head and back for protection. It lives in the dry plains of the western United States. The spiny skin, which conserves water, is an excellent adaptation for an inhabitant of dry areas. This small lizard survives because its color blends with the sand and spiny cacti of its environment.

While one tropical American iguana grows to a length of seven feet, the best known lizard of the Western Hemisphere is probably the five-inch *anole*. In parts of Florida, this graceful lizard can be found in nearly every tree and shrub. It is widely sold as a pet. Because of its ability to change color, the anole is usually called the *chameleon* (ka-*meel*-yun), a name that may properly be applied only to certain Old World lizards. Under the influence of light, temperature, or even its own emotions, the anole may be bright green, brown, or gray. The beautiful collared lizards, also iguanas, are found from the southern United States, through Central America, into northern South America.

The *geckos* (*gek*-ohz) are a group of highly specialized lizards. The toes of most geckos are expanded into clinging pads that enable them to run up vertical surfaces and even walk on ceilings. Geckos are the only lizards that can make loud noises. The *skinks* are known for their shiny cylindrical bodies and generally weak legs. In the forests of Africa and the East Indies, skinks are the most abundant reptiles. In the United States they are exceeded in numbers only by the iguanas. Yet they are not often seen because they are shy, retiring animals.

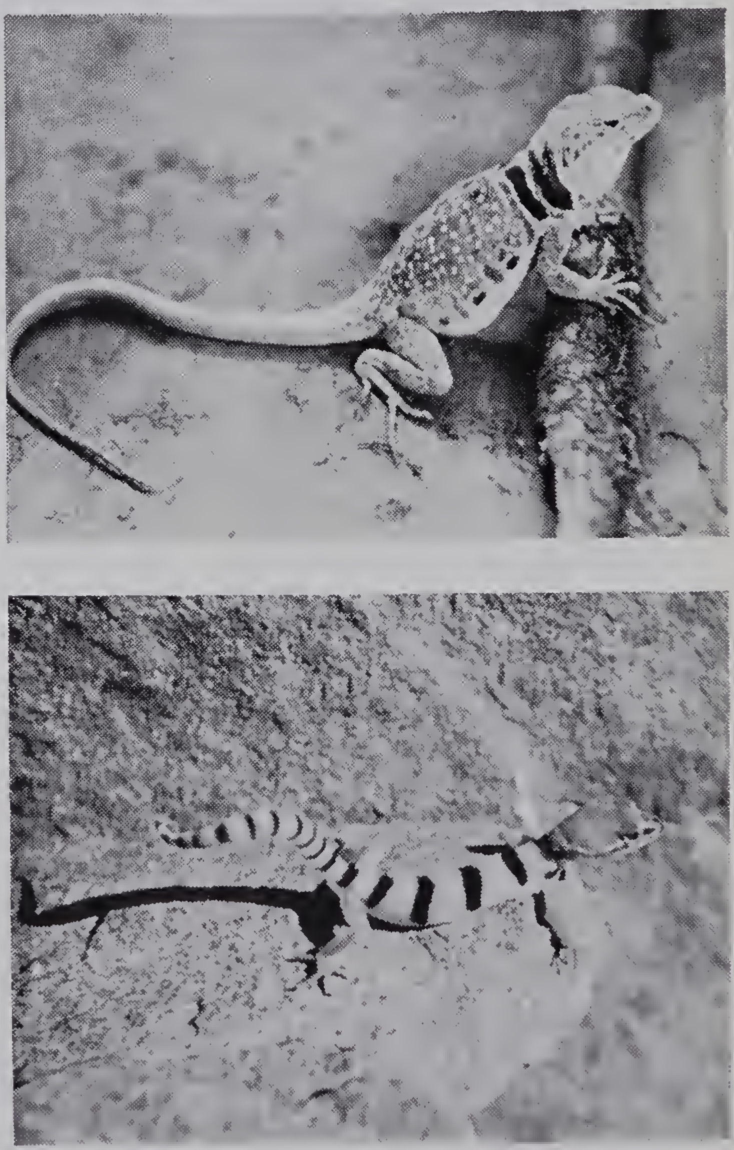
The *Gila* (*hee*-la) *monster,* of southwestern United States and Mexico, and its close relative, the *beaded lizard* of Mexico, are the only poisonous lizards. The name "monster" is misleading, for a large Gila monster is less than two feet long. Poison glands are situated in the rear of the lower jaw.

Grooved teeth are found in both jaws. The venom does not flow through the teeth (as in snakes), but the Gila monster clings tenaciously and shakes its head from side to side, thus allowing the venom to enter the wound. The toxins of the venom are neurotoxic, affecting the nerves that control the victim's breathing. Even though few human beings die of Gila monster bites, these lizards should be treated with the same respect given to venomous snakes.

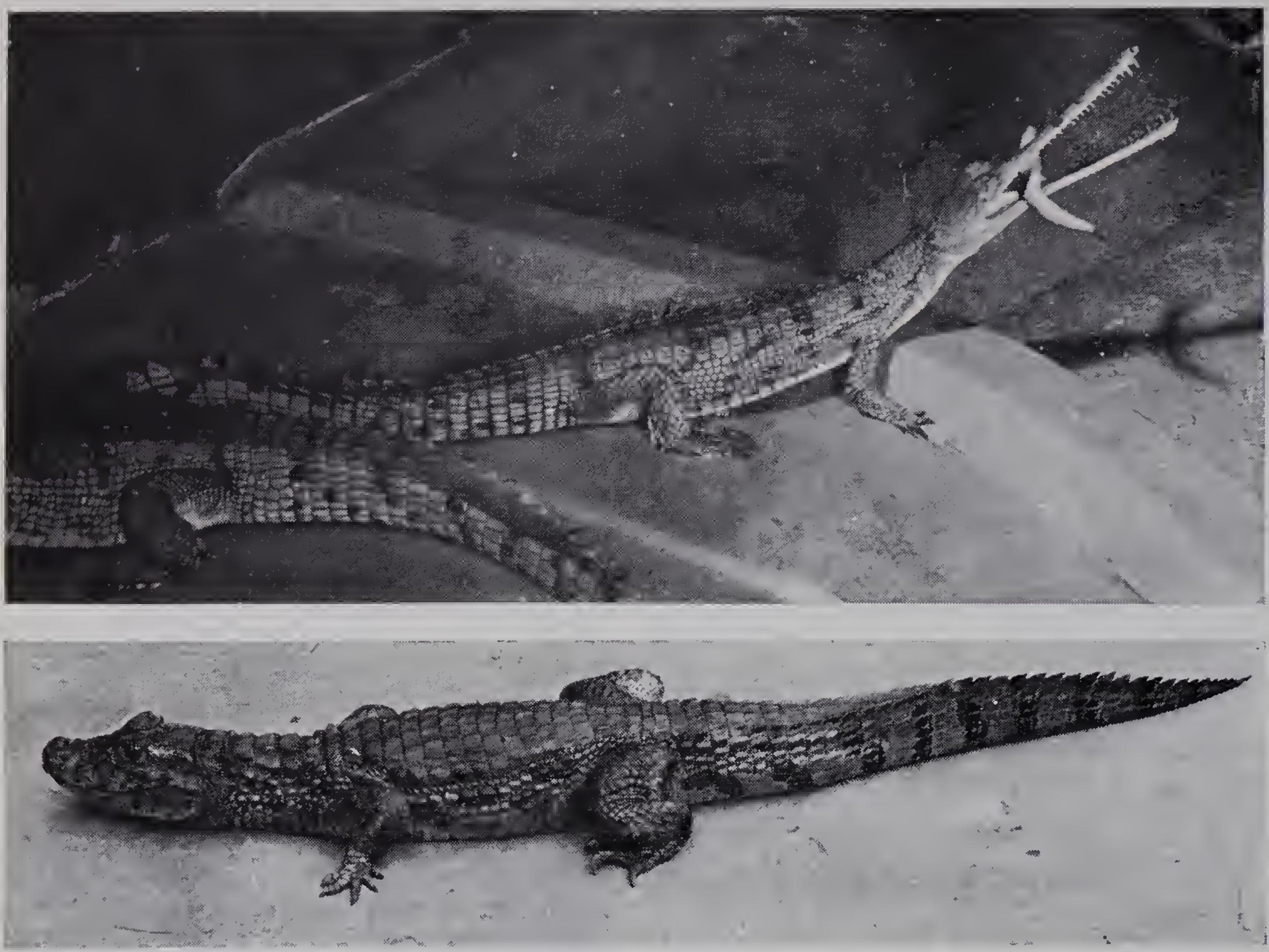
The largest lizards in the world belong to a family called the *monitor lizards.* Monitors are closely related to the ancient lizards that are thought to have given rise to the snakes. Although they do not look like snakes, monitors have several adaptations found in snakes. Several of them are at home in water. The largest monitor is the Komodo dragon, which attains a length of 10 feet and may weigh 300 pounds. It inhabits Komodo Island and several neighboring islets in the East Indies. Except for an inability to spout fire, monitor lizards have all of the classical characteristics of the mythical dragons. Two of the more interesting lizards are depicted in Fig. 36–9.

The crocodilians. The crocodilians and their extinct relatives reached their supremacy in the late Mesozoic Era. They were found in all types of environments, but they thrived only in water. Crocodilians like today's alligators and crocodiles appeared in the Cretaceous period. The modern crocodilians have survived from ancient times because their ancestors developed a means of breathing while in the water — even with their mouths open. Raised nostrils at the end of the snout are connected to the throat by an air passage in the skull. At the back of the mouth is a fleshy valve that prevents water from entering the lungs when the mouth is open. Thus, crocodilians can lie in the water with only the nostrils and eyes above the surface. Unsuspecting animals are often too close to escape by the time they see the predator, or they may be totally unaware of the crocodilian's presence until they are grasped by the animal's powerful jaws.

Compared to the large number of crocodilian species that inhabited the seas in the days of the dinosaurs, only a few survive. About twenty-five living species of *alligators, caimans* (*kay-manz*), *crocodiles,* and *gavials* make up the order Crocodilia. All live in the



36-9 The collared lizard (top) and the banded gecko (bottom) are shy, harmless little reptiles. (American Musuem of Natural History)



36-10 The young Indian gavial feeding on a small fish and the sluggish-looking caiman are representatives of the crocodilian order. (N.Y. Zoological Society)

tropical and subtropical zones. All are very similar to one another, differing in such small ways as length and width of snout, the arrangement of scales, and the arrangement of teeth. Crocodiles are more aquatic than alligators. They are distinguished from alligators by a triangular head and a pointed snout, and by a tooth on each side of the lower jaw which fits into notches on the outside of the upper jaw. Two members of the order Crocodilia are shown in Fig. 36–10.

Alligator hide is of great value for making fine leather, and baby alligators are in great demand as pets. Because of the danger of exterminating the American alligator, the United States has outlawed the collecting of the animals for hide or pets. Most "alligator" hides and baby "alligators" sold in the United States today are in reality the skins and babies of the South American caiman, which is disappearing from large areas of South America. If kept in an aquarium at room temperature and fed regularly on insects, fish, or pieces of raw meat, caimans will live for a long time in capitivity.

The turtles. Biologists speak of turtles that live on land as *tortoises*. These hard-shelled, slow-moving turtles have strong feet and claws for walking on land and digging. Most tortoises are vegetarians, living on a variety of plant foods. Several of the hard-shelled, fresh-water, edible turtles are known as *terrapins*. These turtles are found in markets in many sections of the country. The large ocean-dwelling forms with limbs in the form of flippers are *true turtles.* However, for convenience, we shall refer to all of them as turtles.

If you want to know what the earliest reptiles were like, examine a turtle. It has changed but little in the past 200 million years. This ancient reptile form outdates even the lizards and the dinosaurs, first appearing in the Jurassic period.

The turtle seems to have been nature's experiment with armored vertebrates. The curious body structure was highly successful in one sense, since the animal has survived for such a long time. However, of the more than 7,000 species of reptiles, only 300 are turtles. It seems that the turtles have neither increased nor decreased in number since very ancient times.

It is possible that turtles actually reversed the trend of vertebrates to move from water to land. The ancestors of turtles might have been land animals. Although a few still live on land, most are primarily water-dwellers. But since they are reptiles, all turtles come to the land to lay their eggs.

Several important adaptations have made it possible for turtles to persist for so many years. Most significant was the development of a boxlike shell. The upper and lower shells are connected to each other along the sides, and many turtles can withdraw the head and feet into the shell. Although we often think of turtles as slow and stupid, their adaptation for protection at the expense of movement is the main key to their success.

It is not certain just how much shell the first turtles possessed, but some modern turtles are almost entirely enclosed, while others have greatly reduced shells. In the soft-shelled turtles, the horny shell has been replaced by a leathery skin, but there is a well-developed bony shell beneath the skin. These turtles have flattened bodies which enable them to lie concealed at the bottom of a lake or pond. A very long neck enables these active predators to capture unsuspecting prey. The upper shell of the snapping turtle is an excellent cover, but the lower shell is small. Still, it has excellent protection with its large head and powerful jaws. The typical sea turtles have large upper shells, but the lower shells are somewhat reduced. They can escape from their enemies because their flippers enable them to swim efficiently. Only when they come ashore to sun themselves or lay their eggs are the sea turtles at the mercy of their enemies. If they are turned on their backs on land, they are totally helpless.

Turtles possess valuable adaptations other than their shells. The horny toothless beak is an efficient shearing mechanism which permits the animal to eat meat or plants. Their legs are strong and heavy. Turtles can remain completely submerged in water for long periods of time. Some species have developed a very efficient substitute for gills. Sea turtles are able to absorb oxygen from the water through membraneous areas in both the cloaca and throat.

Although most turtles live in water, the tortoise has become a land dweller, with some living in dry desert conditions. It is a mystery how tortoises became established on islands far from any mainland, but they are found on islands in the Pacific and Indian oceans. The giant tortoises of the Galapagos Islands in the eastern Pacific were extremely plentiful before the arrival of civilized man and his domesticated animals. A number of species of the

36-11 The giant tortoise (left) of the Galapagos Islands off the South American Coast and the gopher tortoise are representative turtles. (Left: American Museum of Natural History; right: N.Y. Zoological Society)

Galapagos tortoises are found on the islands. When Charles Darwin visited these islands during his trip around the world, he observed the different species. These animals contributed to the development of Darwin's theory of evolution.

Structure of the turtle. The upper shell, or ***carapace*** (*kar*-a-pace), of a turtle is covered with epidermal plates, or ***shields***, arranged in a symmetrical pattern. While these shields vary in number and arrangement in various kinds of turtles, they are the same in all members of a species. The shields vary in color and in markings. Beneath the shields are bony plates which are fused together to form a protective case. The shape and arrangement of these bony plates does not match the epidermal shields above them. The lower shell, or ***plastron***, has similar epidermal shields covering bony plates. The carapace and plastron join on the sides in a bony ***bridge.***

The head of a turtle is generally pointed or triangular. The mouth lacks teeth, but the margins of the jaws form a sharp beak with which the turtle bites off chunks of food. There is a pair of nostrils at the tip of the head, making it possible for a turtle to submerge in the water, leaving only the tip of the head above the surface for breathing air. The eyes are well developed and are protected by three eyelids. In addition to fleshly upper and lower eyelids, the turtle has a transparent nictitating membrane which closes over the eyeball from the front corner of the eye. A smooth tympanic membrane lies just behind the angle of the upper and lower jaws.

The limbs of most turtles are short and, in most species, have five toes provided with claws. The feet vary in the amount of webbing between the toes. The skin covering the limbs is tough and scale-covered. The tails of turtles vary greatly in length.

IN CONCLUSION

Since the reptiles were able to occupy a wider range of environmental conditions than their amphibian ancestors, they have been more successful. While they may equal the mammals in variety of adaptations, they cannot compete with either birds or mammals because they do not have the ability to regulate their internal temperature. They are further limited by their small brains. Some early reptiles developed warm-bloodedness and larger brains, and are thought to have given rise to the first mammals. Reptiles have been most successful in the tropics, but even in most tropical regions they are secondary to the higher animals.

In the next chapter, we will study the birds, which, despite their covering of feathers, can be thought of as reptiles with some significant improvements.

BIOLOGICALLY SPEAKING

amniote egg
antivenin
bridge
carapace
caterpillar movement
elastic ligament
hemotoxin
Jacobson's organ
lateral undulatory movement
neurotoxin
oviparous
ovoviviparous
parietal eye
plastron
quadrate bone
Reptilia
scute
septum
shield
side winding
venom
viviparous

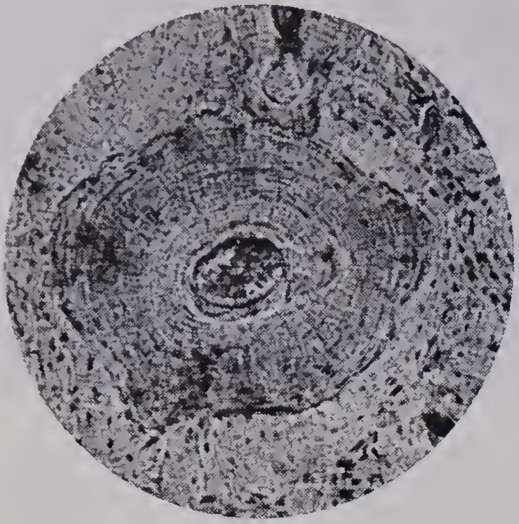
QUESTIONS FOR REVIEW

1. What factors could have enabled the reptiles to invade the land?
2. Why is it difficult to determine when the transition from amphibians to reptiles occurred?
3. Name and describe a plant-eating and a flesh-eating dinosaur.
4. What four orders of reptiles are represented in the world today?
5. List seven characteristics that distinguish reptiles from other vertebrates.
6. In what respect is *Sphenodon* an unusual reptile?
7. What use does the snake make of its forked tongue?
8. Describe three methods used by various snakes in capturing prey.
9. How is the snake's jaw structure adapted for swallowing large prey?
10. Describe three forms of movement in snakes.
11. Name the four families of poisonous snakes and differentiate them.
12. Why is the pit an important characteristic of the pit vipers?
13. Name the two types of toxin found in snake venom and describe their effects on the victim.
14. List as many reasons as you can for the success of the crocodilians.
15. What adaptations have enabled the turtle to survive through the ages?

APPLYING PRINCIPLES AND CONCEPTS

1. In what ways are reptiles better suited to land life than are amphibians?
2. Of what significance is the shelled egg of reptiles when compared to the eggs of fishes and frogs?
3. Make a list of possible reasons for the disappearance of the dinosaurs.
4. Account for the fact that many unusual and ancient animals are found today only on islands.

CHAPTER 37



THE BIRDS

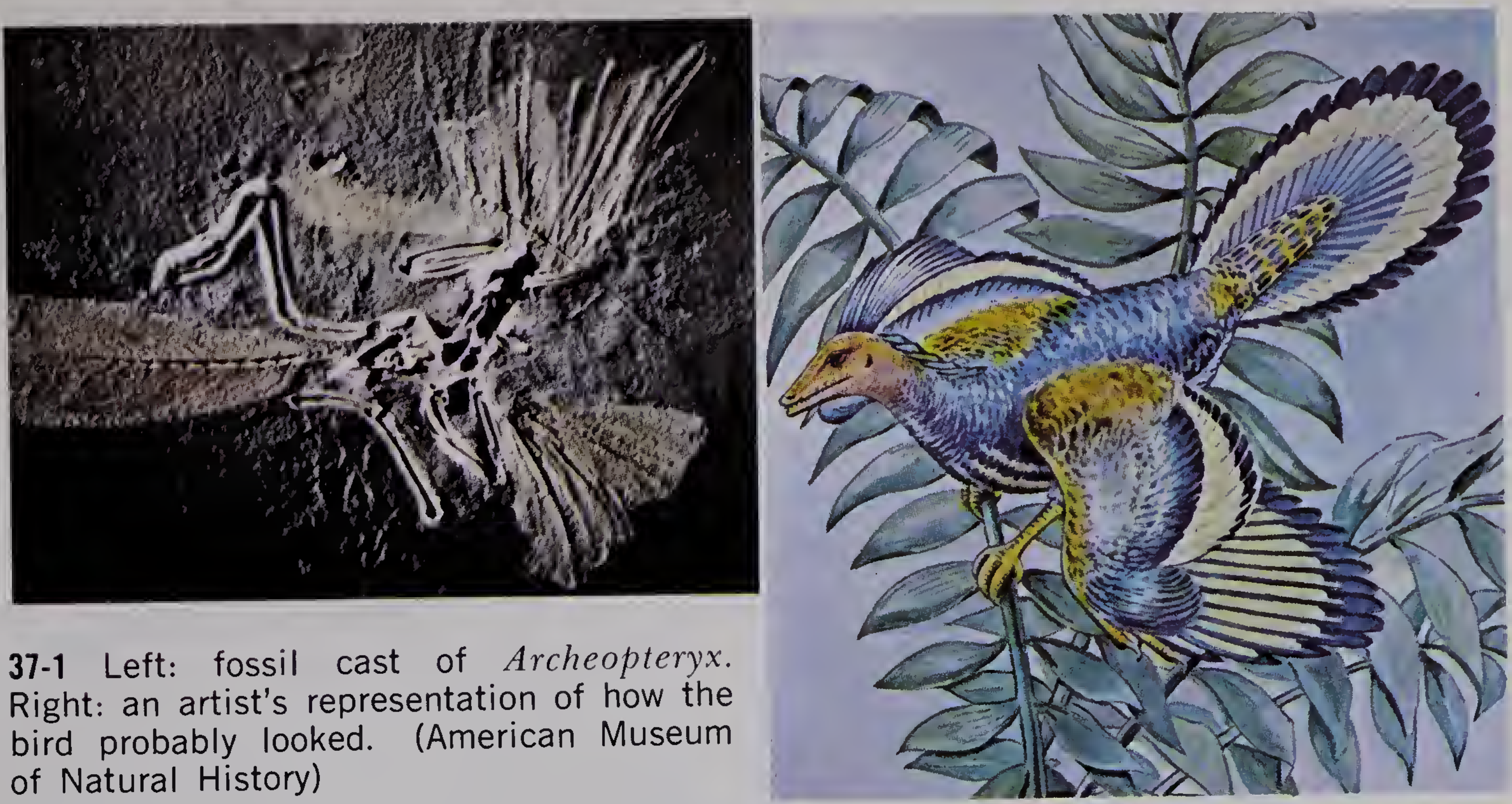
The origin of birds. The birds obviously survived the forces that caused their great reptile companions to disappear, but just how early could they have evolved from the reptiles? In the late 1800's an explorer was digging for fossils in 150-million-year-old Jurassic stone in Bavaria, Germany. As he dug through the layers of stone, he exposed the most ancient bird fossil ever found. Since this was a well-developed bird type, scientists conclude that the first birds appeared more than 200 million years ago.

Fortunately, in addition to a print of the skeleton, the Jurassic fossil included excellent impressions of the long flight feathers on the wings and the double row of tail feathers. Except for these feather impressions, scientists would doubtless have classified the fossil as just another reptile skeleton. Because of its feather prints, the fossil of *Archaeopteryx* (ahr-kee-*ahp*-te-riks) is one of the most important ever found. It was a curious mixture of lizard and bird characteristics. The front of its skull and lower jaws were elongated and narrowed into a beak armed with well-developed reptilian teeth. The neck was long and the body was supported on a pair of strong hind limbs and a typical reptilian tail. The modified forelimbs were weak wings. Extending beyond the feathers of each wing were three clawed fingers, which were probably used in climbing around in trees. The back of *Archaeopteryx* was short and compact, a characteristic that enables the modern bird to fly. Scientists believe that *Archaeopteryx* was able to walk and run in much the same manner as chickens.

During the same period that this strange bird lived, other animals were also taking to the air. These included the Pterodactyls, or flying reptiles. Although they possessed the power of flight, they cannot be considered birds. Flight is not necessarily a bird characteristic. Many birds are flightless, and even some mammals fly. The presence of feathers distinguishes a bird from a reptile. The Pterodactyls were covered by reptilian skin. The flying reptiles of the Jurassic period were probably better fliers than the early birds. The Pterodactyls and dinosaurs lived on the earth for millions of years, but they became extinct. Although all of the birds of the first 150 million years died out, their modified descendants are still with us.

The birds of the Cretaceous period had advanced far along the evolutionary road that gave rise to modern birds. Their fingers had grown together, making the wings stronger. They still retained teeth, but these gradually disappeared and their mouths developed into horny beaks or bills.

Birds as we know them today had evolved by the beginning of the Ceno-



37-1 Left: fossil cast of *Archeopteryx*. Right: an artist's representation of how the bird probably looked. (American Museum of Natural History)

zoic Era. So far as biologists can tell, there has been little or no structural change in birds for more than 50 million years. Most modern birds are very similar to one another. Their variations are the result of adaptations to many different types of life. Modern birds have retained two very conspicuous characteristics from their reptile ancestors — scales on their legs and feet and claws on their toes. Although they never became a dominant form of animal life, the birds must be considered highly successful vertebrates.

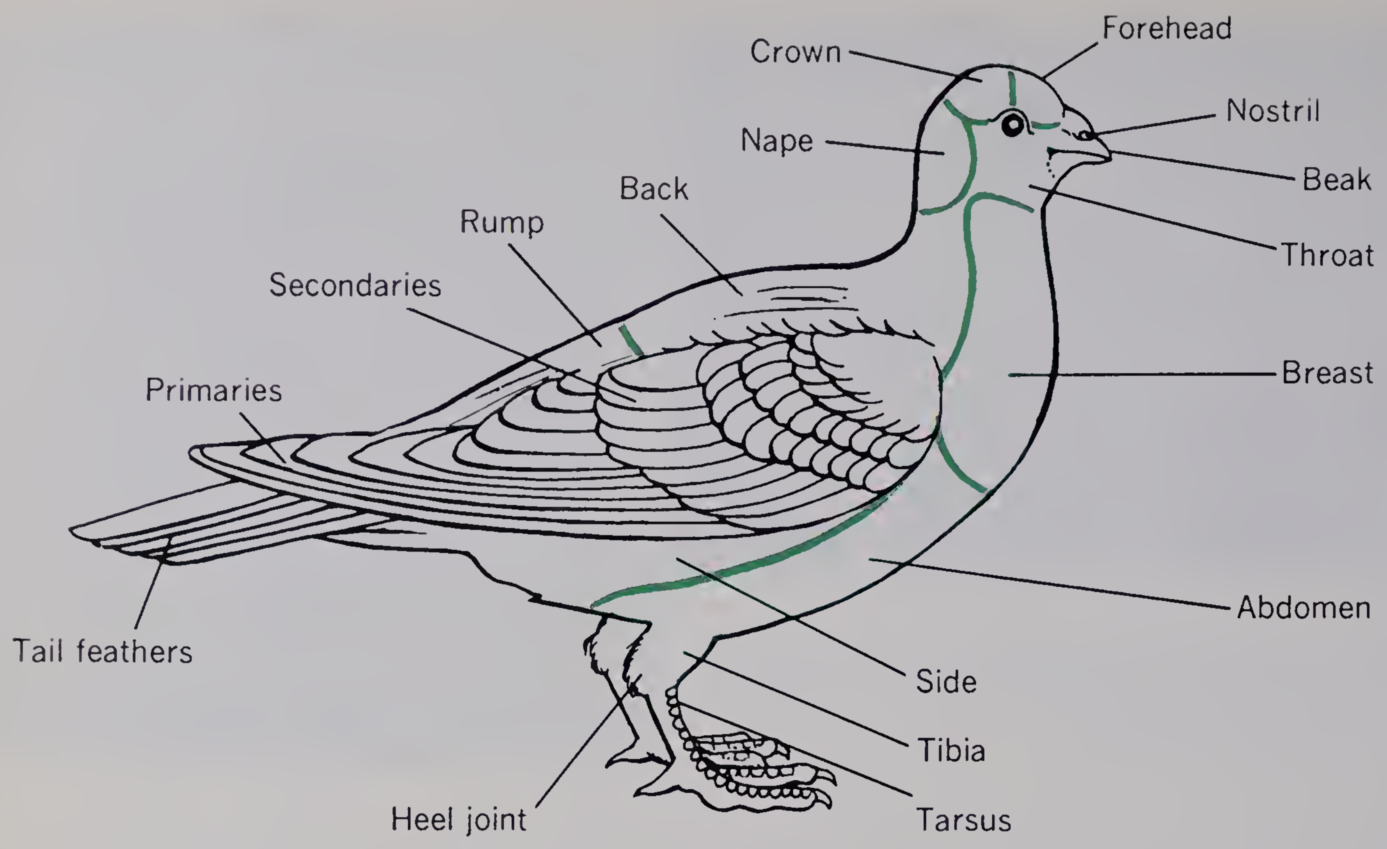
Forms of life unchallenged in the air. Birds have an advantage over all other living things in that they are able to change environments as conditions require. They have been so successful that they have spread their numbers from the jungles of the tropics to the wastelands of the polar regions, and from mountaintop to valley.

Birds vary in size from the tiny hummingbird to the ostrich. The food of various birds includes everything from flower nectar to mammals. The variation in the form and use of the beaks and feet, protective coloration, nesting habits, care of the young, migration, and many other phases of the lives of birds are interesting studies in adaptation.

Characteristics of birds. While birds vary greatly in form, size, diet, and life habits, they have certain characteristics in common. The following distinguish them easily from the other vertebrates:

1. Body covering of feathers.
2. Bones light, porous, and air-filled.
3. Forelimbs (arms) developed as wings for locomotion (in most birds), never for grasping.
4. Body supported on two limbs.
5. Mouth provided with a horny, toothless beak.
6. Eggs covered by a protective shell; in most birds, incubated in a nest.
7. Constant body temperature (warm-blooded).
8. Heart divided into four chambers.

Adaptations for flight. Did you ever compare a bird to an airplane? We probably got our first ideas for airplane design from the birds. The body of the flying bird is streamlined and cuts through the air with a minimum of resistance. The beak and head are



37-2 External view of a bird with the various body parts labelled.

pointed and also serve to reduce air resistance. The body itself is made smooth by feathers. The body tapers at the tail, where large feathers act as a steering device. The legs are attached to the body above the center of gravity. Fore-and-aft balance is provided by the head and neck in front and by the legs and tail at the posterior part of the body.

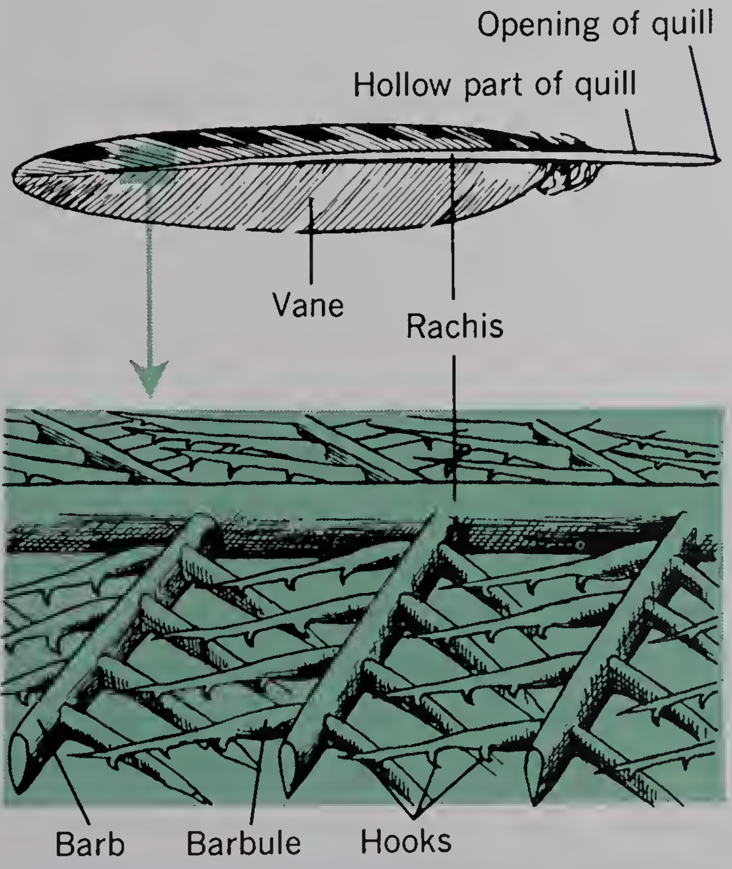
The wings are rounded, thicker on the front edge and tapered on the rear edge. We have duplicated this general shape in the airplane wing. The wings of a bird can be tilted to give upsweep or downsweep or act as a brake. The wings of an airplane have ailerons (a movable part that functions in lateral control), and the airplane tail has a rudder and elevators to accomplish the same purpose. The porous bones of the bird give maximum support with minimum weight, while we have learned to use aluminum and magnesium, both strong, light metals, in airplane construction. Most birds pull their feet against the body in flight. Did you ever watch an airplane fold its landing gear?

Structure and functions of feathers. Strange as it may seem, feathers are modified scales. Feathers develop from pits in the skin. They grow in lines that lie in only certain regions of skin. But the feathers spread out to cover featherless regions.

There are four kinds of feathers. Soft ***down feathers*** form the plumage of newly hatched birds. In older birds, especially waterfowl, they form an insulation close to the skin. Down reduces heat loss so efficiently that a bird can fly through cold winter air and still maintain a body temperature of over 100° F. The slender hairlike feathers having a tuft on the end are known as ***filoplumes.***

Contour feathers cover the body and round out the angles, giving the bird a smooth outline. They also form an effective shield against injury and provide the coloration so important in the life of a bird. Often the female blends more closely with the surroundings than her brightly colored mate. ***Quill feathers*** grow in the wing and tail. These large feathers provide the surface the bird needs in flying and steering in flight.

Figure 37–3 shows the structure of a quill feather. A broad flat ***vane*** spreads from a central axis, the ***rachis*** (*ray*-kis). The rachis ends in a hollow ***quill.*** If you magnify the vane, you can see the many rays or ***barbs.*** Each barb is like a tiny feather with many projections, the ***barbules*** (little barbs). These are held together with tiny interlocking hooks. This complicated arrangement makes the vane strong, light, and elastic. If a vane is split, the bird shakes its feathers and locks the barbules together again; or it may preen the feather by drawing it through its beak, making it whole again. The rachis is grooved and the quill hollow, a condition that gives a feather the greatest strength with the least weight. At the base of the quill is an opening through which nourishment is supplied while the feather is growing.

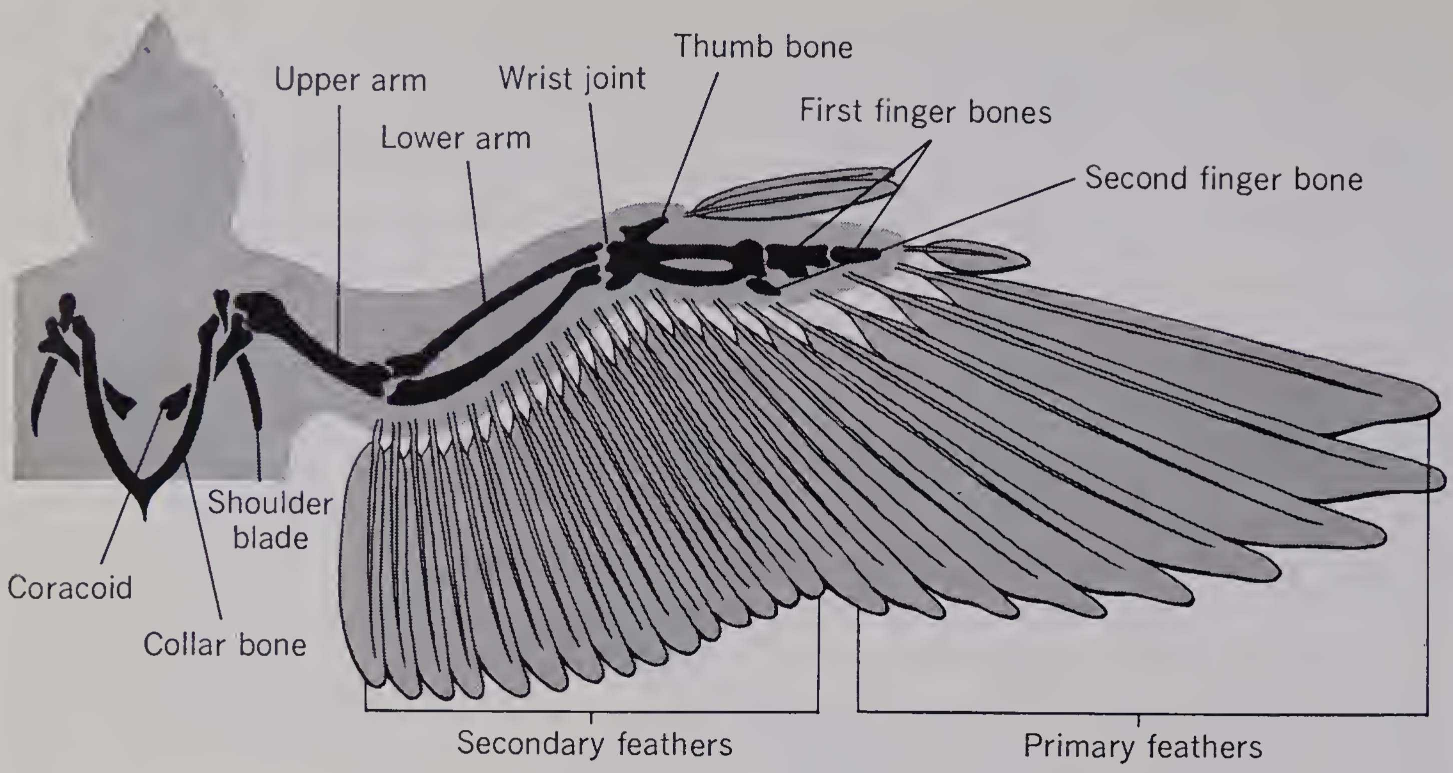


37-3 This diagram shows the structure of a quill feather. The enlargement on the bottom illustrates a portion of the rachis and the vane as seen under a microscope.

The vane of the wing feather is wider on one side of the rachis than the other. When the wing strikes the air in a power stroke, the vane turns up and rests against its neighbor. On the return stroke, it is free to turn back. The air passes through the wing as each feather turns slightly on its axis (feathering), and the wing meets less air resistance.

You have probably noticed birds oiling their feathers after a bath or a swim. Many birds transfer oil from a gland at the base of the tail and spread it over the surface of the feathers, which makes them waterproof. Oil on the feathers is vital to swimming and diving birds such as ducks, geese, swans, loons, and grebes. This oil not only prevents water from penetrating the feathers to the skin, it also makes the birds buoyant and prevents chilling of the body.

Molting in birds. The bird sheds its feathers at least once a year. Feathers, especially those of the wings and tail, may be lost or broken, and since molting usually occurs in the late summer, the bird is provided with new quills before the fall migrations. A second partial molt often occurs in the spring before the breeding season. This molt provides the bright breeding plumage of many birds. In some species, including the ptarmigan, two complete seasonal molts occur. The early summer molt provides a plumage that blends with rocks and soil. The fall molt arrays the ptarmigan in a snow-white winter plumage.



37-4 The wing of a bird shows a greatly lengthened "hand" region and a reduced number of "fingers."

The new feathers grow from the same pits from which the old ones were shed. In most species the wing feathers are shed gradually and in pairs, thus allowing the bird to fly during the molt. Many water birds, including ducks, lose their flight feathers all at once. They must hide from their enemies until new feathers grow in.

A bird's wing – a modified forelimb adapted entirely for flight. You can see the resemblance to your own arm if you examine a chicken wing closely. The upper arm is a large single bone which is attached to the shoulder at a ball-and-socket joint (Fig. 37–4). The part corresponding to the lower arm has two bones like your own. The end section includes the wrist and the hand. This is covered with skin and contains the partial bone structure of three fingers.

The shoulders are braced by three bones in a tripod arrangement: the shoulder blades are embedded in the muscles of the back above the ribs; the collarbone (wishbone) extends from each shoulder and fuses in front of the breastbone, forming a V-shaped bone; and the coracoid bones also brace the shoulder against the breastbone. Thus the wing is firmly braced to withstand the tremendous force required in flying.

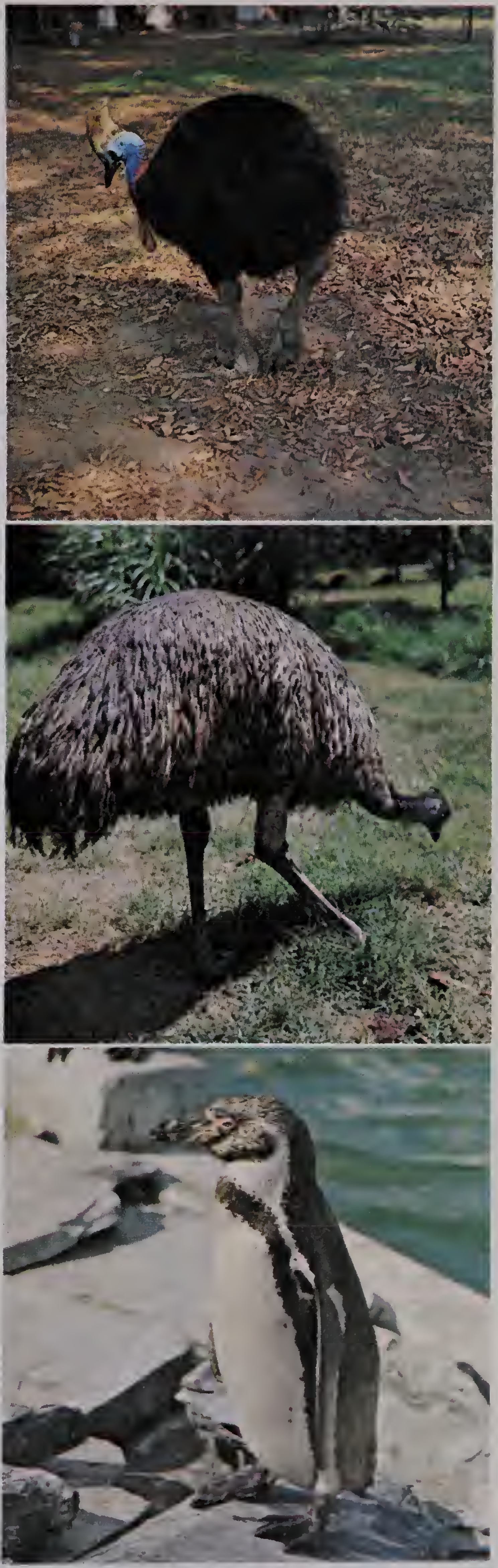
The muscles of the lower arm bend the hand at the wrist. Those of the upper arm move the lower arm. These muscles are involved in folding the wings. But the movement of the wings in flight is largely a movement at the shoulder. These muscles are enormous and in many birds make up one third or more of the whole body weight. The breast muscles are attached to the greatly enlarged breastbone. These muscles of a chicken or turkey are tender and light in color because the birds do not fly. Tendons from these muscles pass over the shoulders like ropes over pulleys, giving tremendous leverage.

The longest quill feathers, the ***primaries***, grow from the end section of the wing, or modified hand, where leverage is the greatest. ***Secondaries*** grow from the second section of the wing, or modified forearm. The lower portion of both of these sets of quill feathers is covered with smaller feathers known as *coverts*. The secondaries in turn are covered by other rows both above and below. The outline of the wing as a whole is concave on the lower side, thick on the forward edge, and thin and flexible on the rear edge and tip — a perfect design for flight.

Motion of the wings in flight. We might compare the motion of a bird's wings in flight to a horizontal figure eight — down and back, up and forward. The down stroke is the power stroke. The upward movement returns the wing to position for another power stroke. These two actions of the wing require two sets of muscles, arranged in layers on the breast. You may have noticed that these layers separate on the breast of a chicken. The tougher muscles of the outer layer pull the wing down in a power stroke. Those of the more tender inner layer raise the wing for the next stroke.

Flightless birds. In many parts of the world, there are birds that have lost the ability to fly. The best known are the ostrich of Africa and the penguin of the Southern Hemisphere.

Most flightless birds have succeeded in life only because they live in areas that are free of predators. Several, like the giant elephant bird of Madagascar, the dodo of the Mascarene Islands, and the moas of New Zealand, became extinct only after the arrival of man and his pets. Others, like the ostrich, the rheas, and the cassowaries survive among predators only because they have exceptionally strong legs and keen vision.



37-5 The cassowary and the emu of Australia and the penguin are flightless birds. (Top and middle: Walter Dawn; bottom: Annan Photo Features)

Penguins are interesting birds. Although they are flightless, their wings are well developed. They use their wings for swimming through the water. Their webbed feet serve them well as rudders. Penguins have the keeled breast that most flightless birds lack. This adaptation may be related to the development of muscles used in swimming.

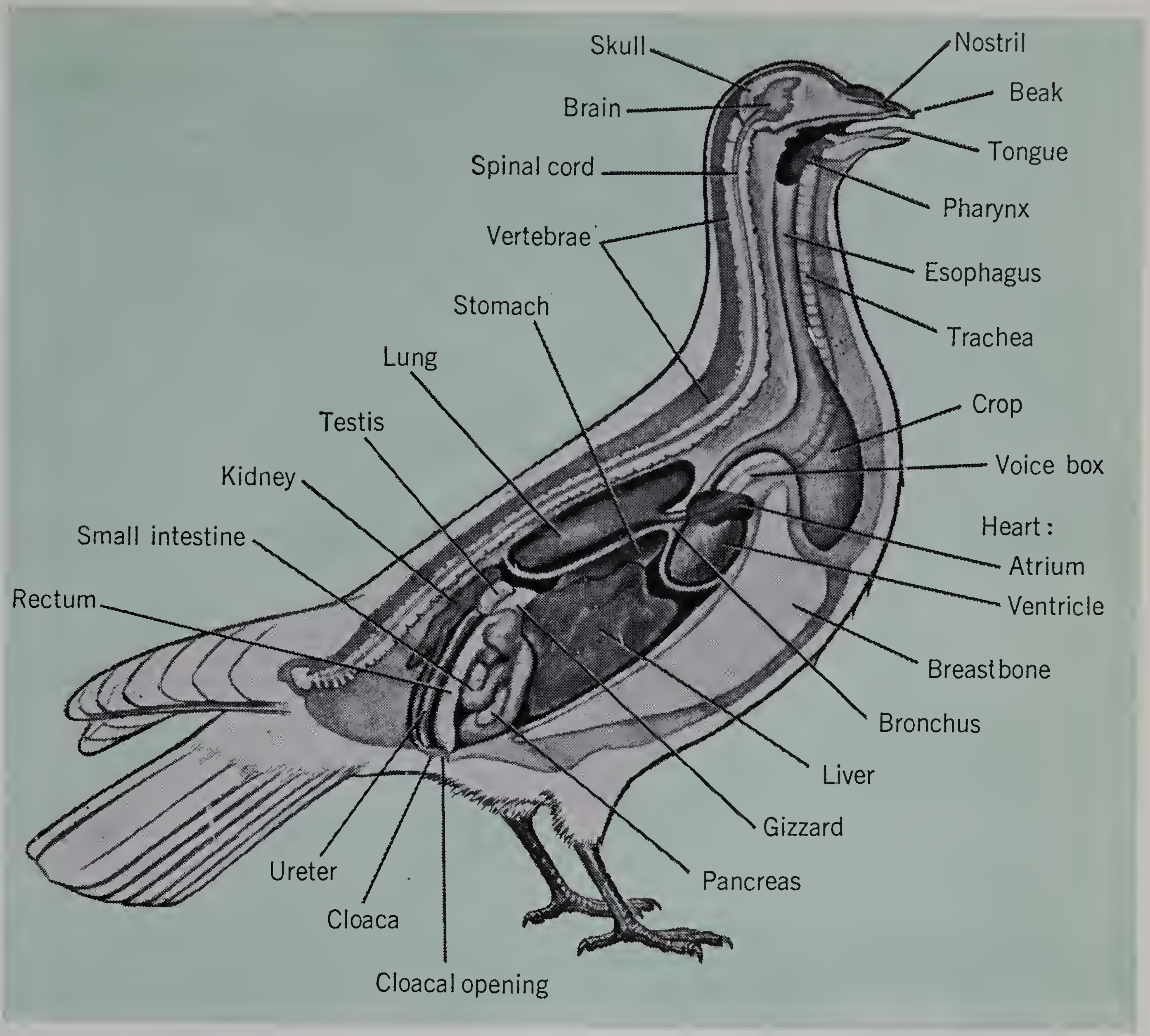
Adaptations for life – birds' feet and beaks. By examining the beak and feet of a bird, it is possible to draw some definite conclusions about the life and diet of the bird. The feet of various birds differ widely in structure, depending on the particular purpose for which they are used. Birds may use their feet for locomotion, to help obtain food, to aid in nest-building, for offense and defense. Most birds walk on their toes. What appears to be the first leg bone is actually a foot bone. The feet of ground birds are adapted for scratching. Most swimming birds have webbed feet, and the legs are set far back on the body, which makes the birds awkward on land. But in water, these birds are very graceful. Birds with very long legs are well adapted for wading or walking in tall grasses, and they have very long toes for balance. Hawks and other flesh-eating birds have strong feet with long sharp claws or talons for capturing animals. Some birds, such as the woodpecker, have toes arranged two in front and two in back for climbing.

In much the same way the beaks of birds are adapted to perform different functions. It is possible to learn much about the diets of birds by studying the shape of the beak. Seed-eating birds, like finches, have strong thick beaks for crushing the seeds. Thinner beaks are found in insect-eating birds like warblers. Probing birds such as the woodcock have very long beaks. Birds of prey have hooked beaks for tearing flesh. Some ducks have beaks that are adapted for straining food particles out of mud. Hummingbirds and a few others have long, slender beaks that can sip nectar from the deep throats of flowers. Birds belonging to entirely different groups may have similar beaks that perform similar functions. Unlike beaks are sometimes found among members of the same group. Figure 37–7 illustrates the relationship between beaks and feet in some birds.

In spite of all the differences in feet and beaks, the birds have more structural similarities than any other class of vertebrates and this can be explained. Isolation leads to more pronounced structural variation. Most vertebrates are isolated by oceans, mountains, and deserts. But birds, with their ability to fly, are able to cross many of the barriers that isolate other vertebrates.

Feeding activities. The bird is the first warm-blooded animal we have studied. A constant body temperature as high as 112° F is maintained in some species. The maintenance of this temperature, together with the tremendous muscular exertion during flight, requires a high rate of metabolism. This requires a large amount of food — the fuel for a metabolic furnace. Thus birds spend much of their time eating. To say that someone "eats like a bird" is actually to say that he is a glutton.

Birds feed on a great variety of animal and plant life. Some eat insects. Others eat seeds. Some destroy rodents, fishes, and other birds. Some eat carrion (decaying flesh), and others sip the nectar of flowers or the honey produced by bees. Among the birds using animals for food are large birds


Skull
Nostril
Beak
Brain
Tongue
Spinal cord
Pharynx
Vertebrae
Esophagus
Stomach
Trachea
Lung
Crop
Testis
Voice box
Kidney
Heart:
Small intestine
Atrium
Rectum
Ventricle
Breastbone
Bronchus
Liver
Gizzard
Ureter
Pancreas
Cloaca
Cloacal opening

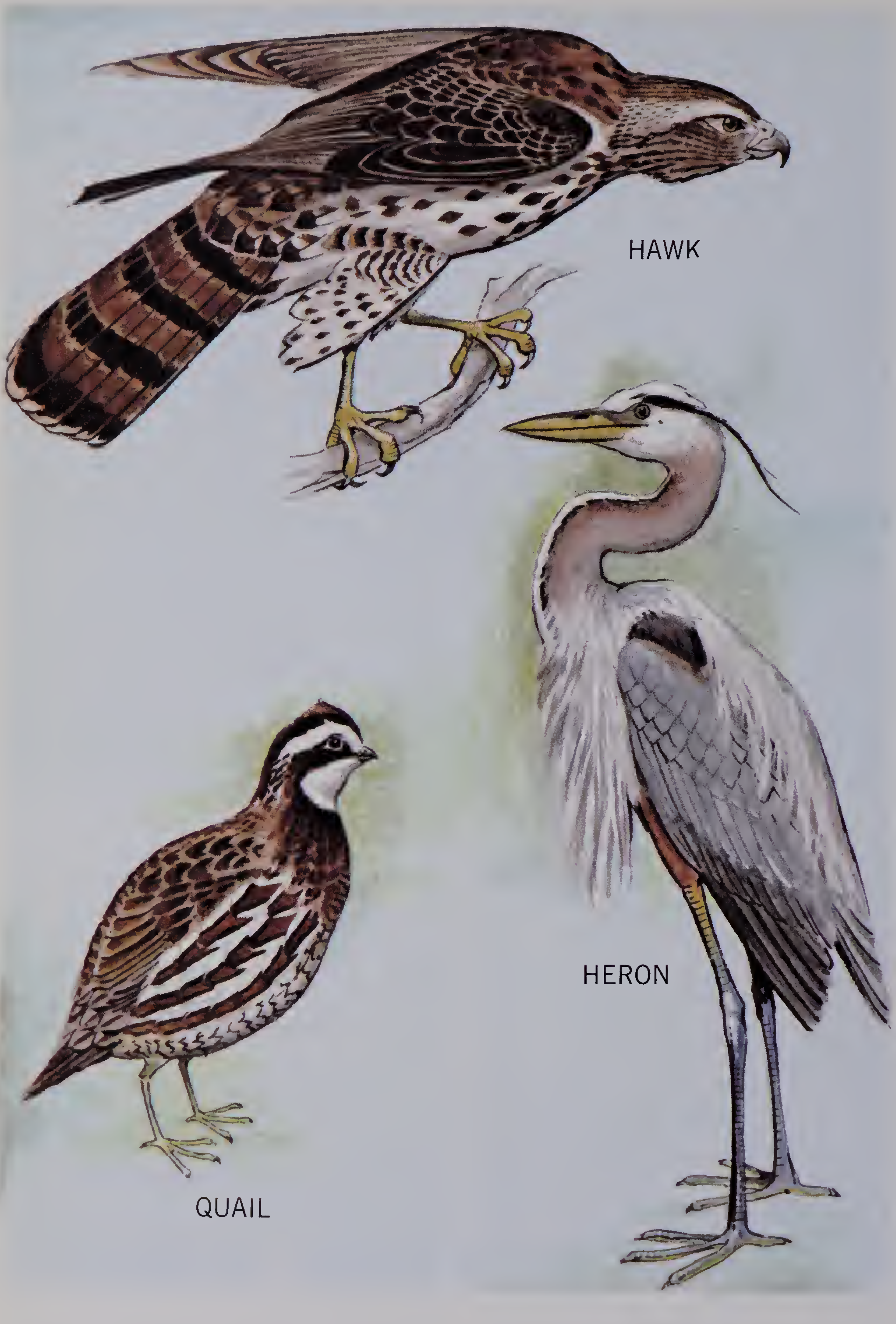
37-6 The internal organs of the bird.

of prey, such as hawks and owls, which help limit the population of rodents, rabbits, and some smaller birds. The loon, grebe, pelican, kingfisher, and several hawks feed largely on fish, which they catch by diving. The best known carrion eaters are the vultures. They have keen vision, which enables them to locate a dead animal as they soar through the air. Probably the largest number of birds that enjoy an animal diet live chiefly on insects, which they catch in the air (swifts), in wood (woodpeckers), on the ground (robins), or on trees (warblers).

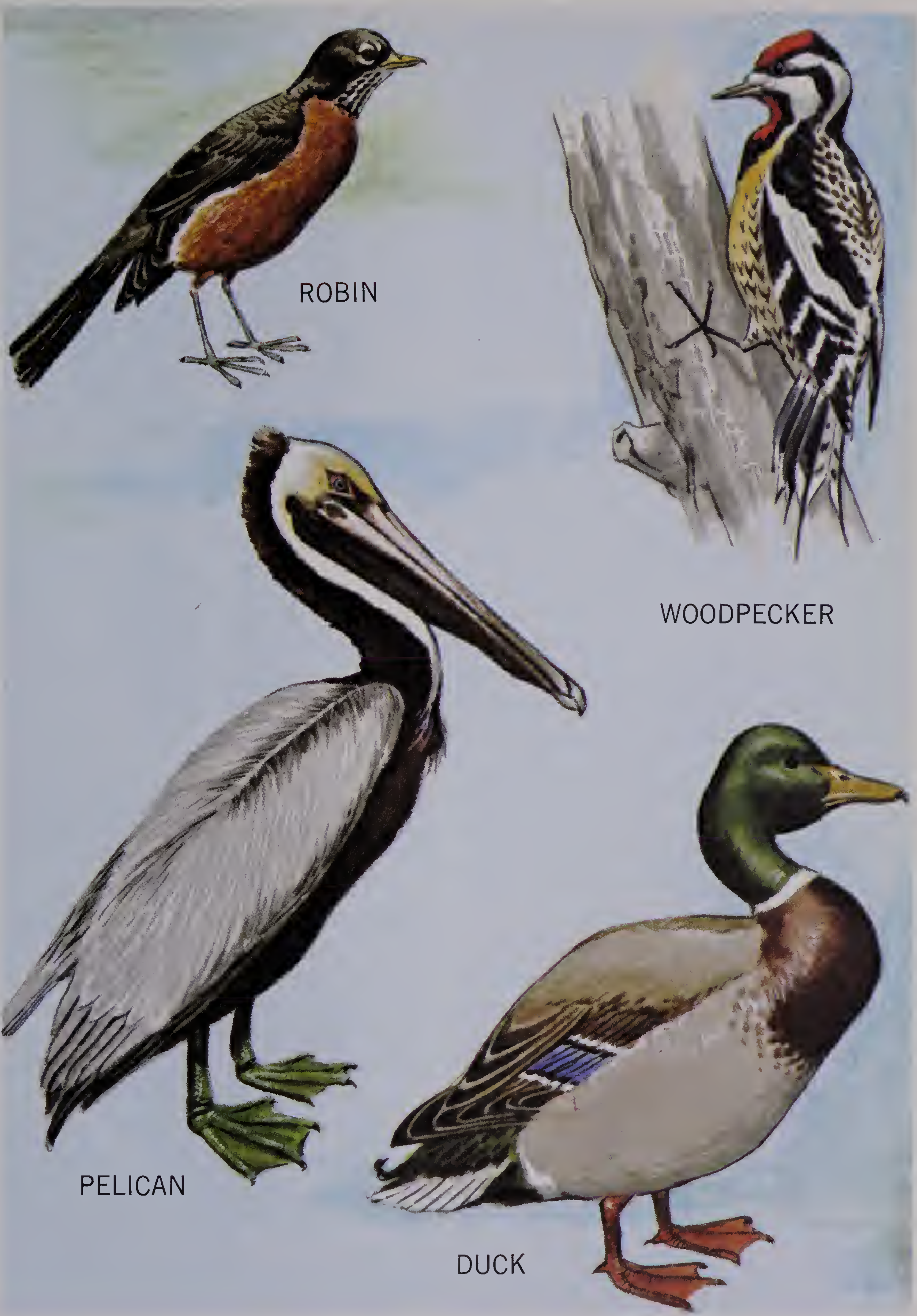
Many birds live almost exclusively on seeds, doing much good by the destruction of weed seeds, while others, such as blackbirds and bobolinks, do considerable damage by their preference for grain, peas, and rice. Various kinds of both wild and cultivated fruits, especially berries, are preferred by certain birds.

Sometimes birds eat the same seeds or fruits that man raises, or they may at times rob his yard of a stray chicken. But careful study has proved that few if any birds do more harm than good. The rest repay many times for eating a small quantity of valuable food.

The digestive system of the bird. Food, swallowed whole, passes down an *esophagus* into a *crop*, located just below



37-7 The feet and beaks of birds vary with their activity and their food. For example, a duck's feet are adapted for swimming while its beak is adapted for scoop-


ROBIN
WOODPECKER
PELICAN
DUCK

ing and straining. For what type of activity would you say each of the other feet shown here is adapted? Also, what type of food would you say each bird ate?

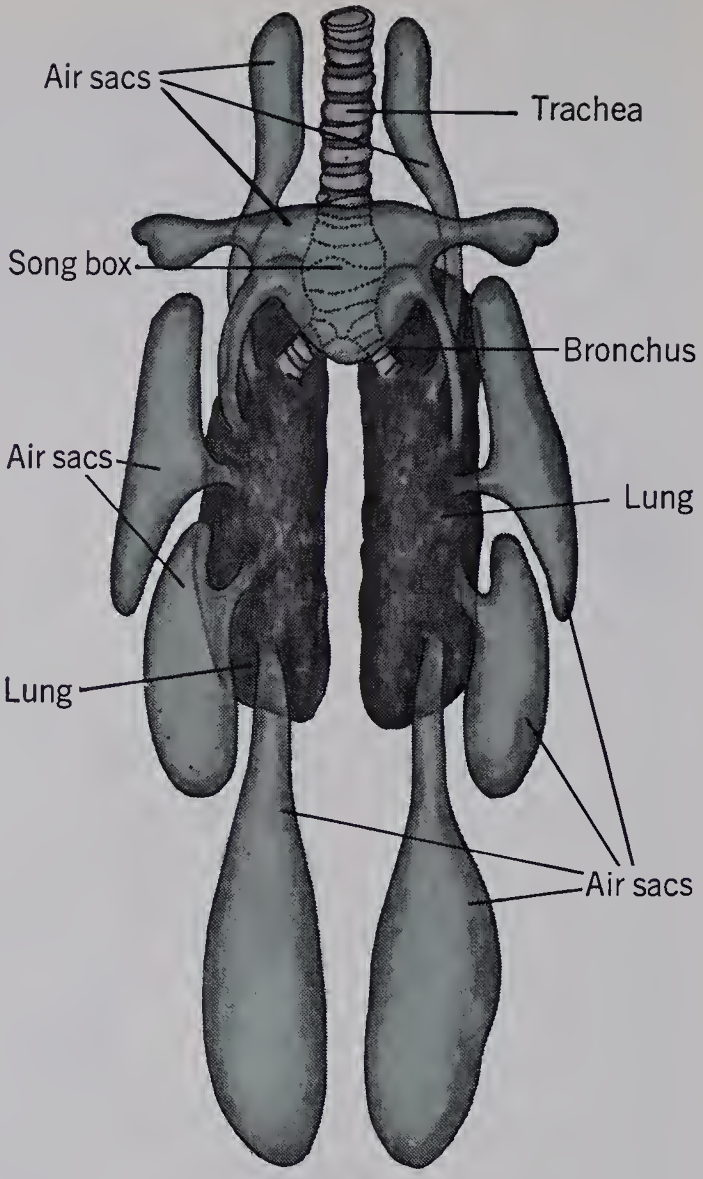
the base of the neck (Fig. 37–6). Here the food is stored and moistened. From the crop, food passes into the first division of the ***stomach*** where glands in the thick walls add a digestive secretion. The stomach content then passes into the second stomach region, the ***gizzard.*** The thick muscular walls of the gizzard, aided by small stones in some species, churn and grind the food. A U-shaped loop of intestine joins a short ***rectum,*** or large intestine, which leads to a ***cloaca*** somewhat like that of the frog.

The two-lobed ***liver*** is large and may or may not have a ***gallbladder*** on the lower side, depending on the species of bird. Bile is poured into the small intestine through two ducts. The ***pancreas*** lies along the U-shaped portion of the intestine and pours its secretion into the intestine through three ducts.

Respiration, circulation, and excretion in the bird. The lungs of a bird lie in the back against the ribs, in the anterior region of the body cavity. The capacity of the lungs is greatly increased by a system of ***air sacs*** that extend from the lungs into the chest area and the abdomen and connect with cavities in the larger bones (Fig. 37–8).

Air is drawn through the nostrils in the beak and down the ***trachea*** and its lower divisions, or ***bronchi,*** to the lungs and air sacs by relaxation of the thoracic and abdominal muscles. Contraction of these muscles forces air out. Though the lungs are small, a rapid rate of respiration fills them often and supplies the blood with the great amount of oxygen necessary to carry on the high rate of oxidation in the body tissues.

The bird's respiratory system is also its principal temperature-regulating system. It has no sweat glands and cannot eliminate heat through its skin. Most excess heat is discharged from the body through the lungs. The air sacs are believed to assist in heat elimination. You may have noticed that birds often pant with their mouths open on a hot day. At times like these, the insulation provided by feathers is more a liability than an asset.



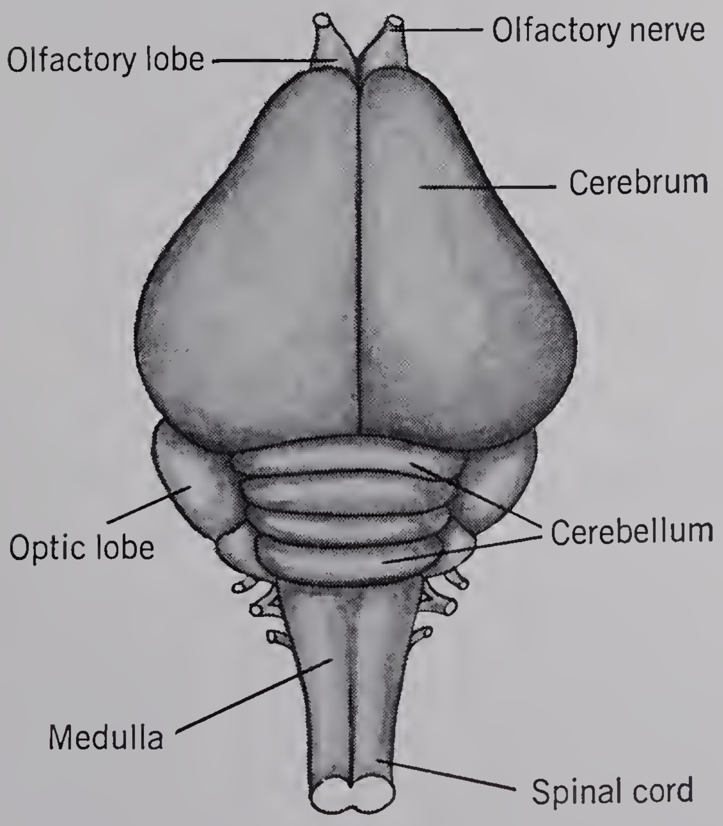
37-8 Because birds are so active their respiratory systems are especially adapted to accomplish rapid oxidation of food and release of energy.

The lungs also supply air for singing. The bird's song is not produced in the throat but at the base of the trachea, where the bronchi begin. Here the ***song box,*** a delicate and highly adjustable structure, is located.

The ***kidneys*** are dark brown, three-lobed organs lying along the back. They excrete ***uric acid,*** a waste product of cell activity. This is discharged with very little water through the ureters into the cloaca, and is then eliminated along with intestinal waste.

The *heart* of a bird is large and powerful. It consists of two thin-walled *atria* and two muscular *ventricles.* The right side of this four-chambered heart receives blood from the body and pumps it to the lungs. Blood returns from the lungs to the left side and is pumped to the body. The heart of the bird beats at an amazing rate. With the bird at rest the beat is several hundred times per minute. Under exertion the heart may beat as many as a thousand times a minute.

The nervous system of a bird. In birds the brain is large and broad, completely filling the cranial cavity. The *olfactory lobes* are small, indicating a poorly developed sense of smell (Fig. 37–9). The *optic lobes* are large, thus accounting for the keen vision of the bird. The hemispheres of the *cerebrum* are the largest of any animal we have discussed thus far. The highly developed instincts of birds center in this brain region. The large *cerebellum* accounts for the excellent muscular coordination of the bird, especially in flight. The *medulla* joins the spinal cord, which extends down the back, encased in vertebrae.



37-9 The structure of the bird's brain. Compare the relative size of the cerebrum to that in the fish and frog brain. What do the optic lobes indicate about the sense of sight?

Sense organs of the bird. The eyes are large, and the sense of sight is very keen. It is said that some birds, especially hawks and owls, have vision eight times as keen as that of man. Owls and certain other birds have excellent vision in reduced light. Birds have a remarkable ability to judge distance, both at close range and at great height. They can drop out of the sky and light on a rock in a stream, fly through a deep woods, or swoop down onto a slender perch. The eyes are protected by an upper and a lower eyelid, as well as by a thin transparent nictitating membrane.

Ear canals are covered by a tuft of feathers. Eustachian tubes lead from the ears to a single opening in the upper wall of the throat. The sense of hearing is very keen, and the ears are especially sensitive to high notes.

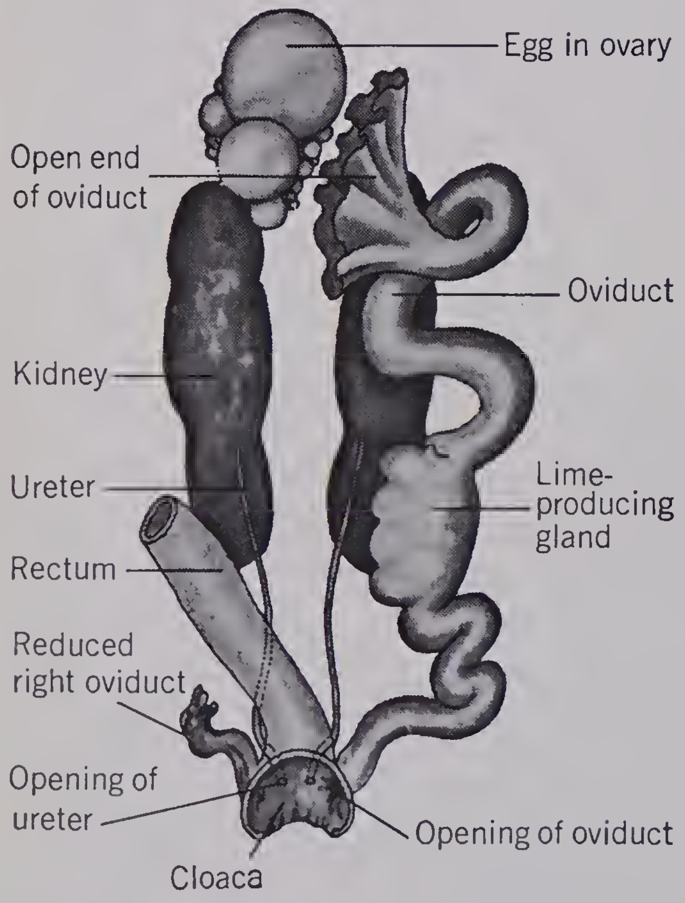
The senses of smell and taste are very poor, a fact due in part to the horny nature of the mouth. The tongue of most birds is small and serves as an organ of touch.

The reproductive system. The oval *testes* of the male bird lie in the back in about the same position we found them in the male frog. Tiny tubes carry sperm to openings in the cloaca. During mating, sperm are deposited in the cloaca of the female.

The female reproductive organs include a single *ovary* in which eggs develop, and a long, coiled *oviduct* which leads to the cloaca (Fig. 37–10). In most birds the right ovary disappears early in life. The absence of one ovary and oviduct is another of the interesting modifications of birds for life in the air.

If you examine a hen you are preparing for dinner, you will find a mass of orange spheres in the region of the back — these are developing ***yolks.*** On the surface of each yolk is a tiny ***egg cell*** surrounded by protoplasm. When a yolk has grown to full size, it is drawn into the upper end of the oviduct by lashing cilia. As the yolk travels down the oviduct, it is surrounded with layers of ***albumen,*** or egg white. Two enclosing membranes form around the albumen. One of these is an amnion, such as we found in the reptile egg. A hard shell is secreted around the membranes by ***lime-producing glands*** in the lower part of the oviduct, before the egg is laid.

Thus, we must distinguish between an egg and an egg cell. The tiny spot surrounded by protoplasm on the side of the yolk will develop into a new organism. It is the only living part of an egg. The protein of the albumen and oils of the yolk are stored nourishment for the developing embryo. The shell prevents drying out, but must be porous enough to admit air. The pores are also large enough to admit bacteria, which accounts for the spoilage of eggs, especially in warm weather.

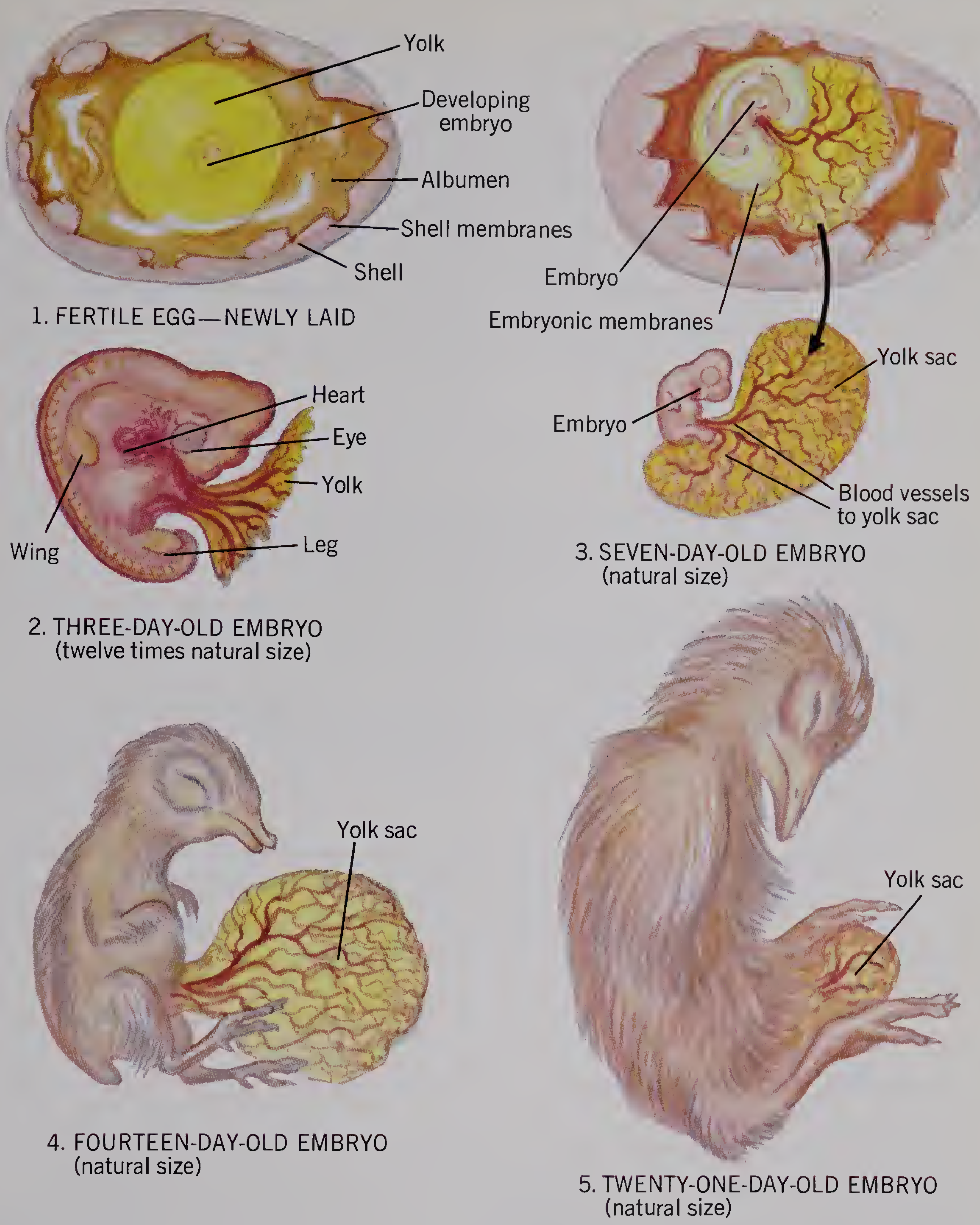


37-10 In this drawing of the reproductive system of the hen, the ovary is shown containing immature eggs.

Incubation and development of a bird. An embryo can develop in an egg only if a sperm has fertilized the egg cell before the shell is formed. Development begins as soon as the egg is incubated, or kept continuously warm. The mother provides this warmth by sitting on the egg. The incubation temperature of most birds is slightly above 100° F.

The time of incubation varies from 13 to 15 days in smaller birds to as many as 40 to 50 days in a large bird. The hen's egg is incubated 21 days (Fig. 37–11). The egg of a duck requires 28 days. It is usually the female which sits on the eggs. However, the male bird takes his turn in some species, including the ostrich. Just before hatching, the baby bird absorbs the remainder of the yolk. The baby bird pushes the shell halves apart and works itself out. Some birds have hardly any body covering when they are hatched. Others are covered with a dense coat of down.

Egg number and parental care. Ducks (except the wood duck), geese, quail, grouse, turkeys, chickens, and other fowl-like birds lay a large number of eggs in a nest on or close to the ground. The eggs are not incubated until the last one is laid. As many as 12 to 15 birds may hatch at the same time. They are fully covered with down and can scratch for their food almost immediately. However, they must be warmed


Yolk
Developing embryo
Albumen
Shell membranes
Shell
Embryo
Embryonic membranes
Heart
Eye
Yolk
Wing
Leg
Yolk sac
Embryo
Blood vessels to yolk sac
Yolk sac
Yolk sac

1. FERTILE EGG—NEWLY LAID

2. THREE-DAY-OLD EMBRYO (twelve times natural size)

3. SEVEN-DAY-OLD EMBRYO (natural size)

4. FOURTEEN-DAY-OLD EMBRYO (natural size)

5. TWENTY-ONE-DAY-OLD EMBRYO (natural size)

37-11 This drawing shows a sectioned view of a fertilized hen's egg and also illustrates some of the stages in the development of the chicken embryo.

and protected by their parents. Birds like the robin, bluebird, sparrow, and warbler usually lay fewer than six eggs. Incubation starts when the last egg is laid. Thus the baby birds hatch at about the same time, but they are helpless and must be fed almost continuously by their parents. They remain in the nest until they are able to fly. Since these birds are protected by one or both parents until maturity, the chances of survival are much greater, and there is need for fewer young to insure continuation of the species.

Hawks and owls usually lay only one to four eggs and incubate them as soon as each is laid. This results in a stairstep family. The young of these birds are also fed in the nest until they are feathered and able to fly.

Most birds are very devoted to their eggs and young. Some will protect the eggs even when they may be stepped on. Normally shy birds will swoop down on an intruder and fiercely attack it, regardless of the size. The killdeer will feign a broken wing and lure an intruder away from the nest. At the other extreme is the cowbird, which lays its eggs in other birds' nests and depends on the other bird to incubate and rear its young.

IN CONCLUSION

Birds show a distinct relationship to the reptiles, becoming a new class as a result of adaptive changes believed to have occurred about 200 million years ago. Birds exhibit the best example in all biology of adaptation for a special kind of life. Their bodies are excellent examples of flight engineering. The special structures they maintain for supremacy in the air has removed them from the possibility of dominance on land.

Flightless birds survive only by possessing strong legs and keen vision, or by living where there are no predators, and many flying birds survive in changing environments only by periodically migrating to regions where there is sufficient food.

During the age of reptiles, while birds were developing their remarkable adaptations for flight, the most efficiently organized animals ever known were beginning a long evolutionary process that eventually gave rise to mammals. In the next chapter, we will learn why the mammals have become the dominant form of animal life.

BIOLOGICALLY SPEAKING

air sac
albumen
barbs
barbules
bronchi
contour feathers
coverts
down feathers
egg cell
filoplume
lime-producing glands
primaries
quill
quill feathers
rachis
rectum
secondaries
song box
uric acid
vane
yolk

QUESTIONS FOR REVIEW

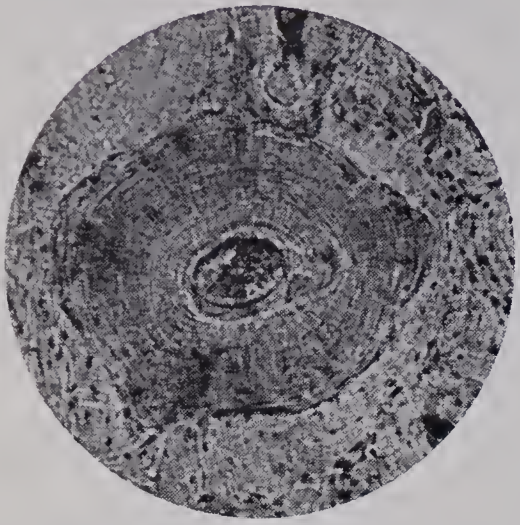
1. Explain why it was fortunate that feathers were fossilized with the bones of *Archaeopteryx*.
2. What characteristics relate birds to reptiles?

3. What are some characteristics of birds that make them ideally suited for life in the air?
4. Give the functions of the four kinds of feathers.
5. Why is oil on the feathers of importance to water birds?
6. Where are the bird's powerful flight muscles located?
7. Explain why the flightless birds are limited to certain parts of the world.
8. How can we learn about the diet and habits of birds by examining their feet and beaks?
9. In what ways are air sacs important to the bird?
10. What advance in structure over the reptile is shown in the bird heart?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss various reasons why birds have achieved success as a group.
2. Explain why the ostrich and other flightless birds are not considered primitive.
3. Compare the amount of food consumed and the rate of respiration in the bird with other vertebrates you have studied.
4. Explain the meaning of the term *warm-blooded* as it applies to birds.
5. Discuss the relationship between parental care and the number of eggs laid.

CHAPTER 38



THE MAMMALS

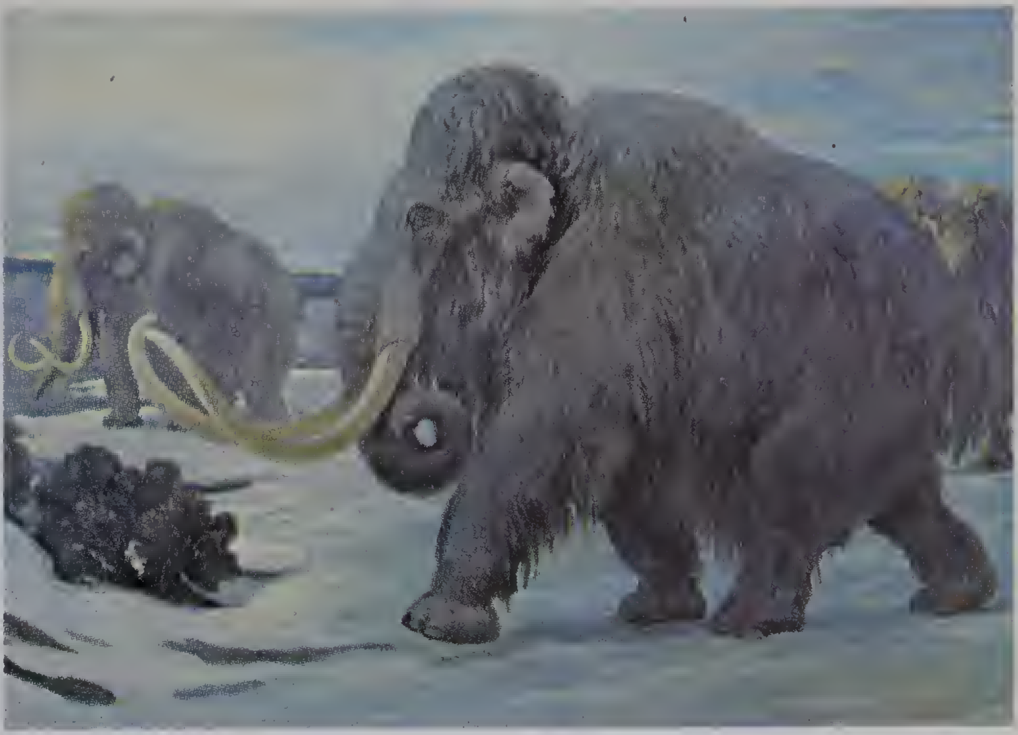
The rise of mammals. Compared with other animals mammals are a recent form of life. Fossils indicate that the earliest mammals appeared about 60 million years ago. At that time the earth was undergoing geological changes that marked the end of the Mesozoic Era and the dawn of the Cenozoic Era (Fig. 13–1, page 183). Prior to this time a warm, humid climate had prevailed over much of the earth. Shallow inland seas and swamps were numerous among the flat land masses. These conditions had favored the giant reptiles that dominated animal life for ages. Then, as though nature were closing one chapter of life to make way for another, continents were uplifted and mountain ranges and high plateaus arose. These changes altered the climate of the continents, resulting in seasonal temperature variations and differences in the precipitation in various continental areas. Forest lands, prairies, plains, arid lands, and deserts came into being. Within a short time most of the reptiles died out, yielding their dominance among land animals to the mammals.

The earliest mammals were small and included forerunners of the squirrel, rat, and mouse. Another of the earliest mammals was a little ancient horse known as *Eohippus* (ee-oh-*hip*-us), which was no larger than a small dog. This curious ancestor of the modern horse had five toes. Other early mammals resembled monkeys. One of the few early mammals that has survived to the present day is the opossum.

From these early beginnings mammals increased in size and became more abundant. Hoofed mammals, including ancient species of the rhinoceros, camel, wild pig, and a larger three-toed horse roamed the forests and grasslands in great herds. Still later, flesh-eating mammals, including the great bear dogs and terrible sabre-toothed cats, flourished, destroying large numbers of hoofed mammals. Near the close of the Cenozoic Era, further cooling of the climate resulted in the age of glaciers. Then prehistoric elephants, called mastodons and mammoths, migrated to Africa through Europe, Asia, and the North American continent.

Many species of ancient mammals perished long ago. However, a large number survived the changing conditions and served as the ancestral stock of the mammals we know today.

Characteristics of mammals. Modern mammals vary in size from the tiny shrew, less than two inches long, to the enormous blue whale, over 100 feet long. In their widely varied forms, mammals are found in all parts of the world except a few Pacific islands. They are for the most part land animals, although some, like the whale, porpoise, and sea cow, are adapted to life in the



38-1 The mammoths are prehistoric mammals that became extinct, probably because they could not adapt to changes in climate. (American Museum of Natural History)

sea. The bats are the only mammals capable of flight.

While mammals vary greatly in body form, size, and mode of living, all have certain characteristics in common:

1. Body mostly covered with hair.
2. Young nourished during development in the body of the mother and born alive, in most mammals; hence, viviparous.
3. Young nourished after birth by milk secreted by the *mammary glands* of the female, a characteristic for which the class is named.
4. Cerebrum highly developed.
5. Diaphragm (breathing muscle) separating the thoracic (chest) cavity from the abdominal cavity.
6. Lungs used for breathing throughout life.
7. Four-chambered heart and high circulatory development with left aortic arch only.
8. Ability to maintain constant body temperature (warm-blooded).
9. Seven cervical (neck) vertebrae, except in the sea cow (manatee) and sloth.
10. Two pairs of limbs, except in the whales, porpoises, and sea cow.

The egg-laying mammals. The most primitive of mammals are the ***monotremes*** (*mahn*-o-treems), represented by the duckbilled platypus and the spiny anteater. These animals are found in Australia and New Guinea. Like their reptilian ancestors, the monotremes lay eggs. Their skeletons still have several reptilian characteristics, and they lack external ears. Biologists believe that the monotremes descended from different reptiles than did other types of mammals.

The *duckbill* is about 12 to 18 inches long. It has waterproof fur, a horny ducklike bill, and feet modified as paddles. Its home is a burrow, dug several feet into a bank, which ends in a grass-filled nest. The duckbill usually lays two or three eggs, which resemble those of reptiles. The eggs are retained in the body of the female for some time before they are laid in a nest. Then she clutches them to her body and rolls into a ball to incubate them. After hatching, the young are nourished on milk from sweat glands of the mother that are analogous to mammary glands.

The elongated toothless jaws of the *spiny anteater* are well adapted for prob-

38-2 The duckbilled platypus. (Australian News and Information Bureau)

ing in ant hills. The animal is well protected by a body covering of sharp spines. It lays two eggs which are placed in a brood pouch on the anteater's lower side. The eggs remain in the brood pouch several weeks before hatching.

The pouched mammals. Perhaps the most familiar examples of the ***marsupials***, or pouched mammals, are the opossum and the kangaroo. The marsupial egg does not contain enough yolk for advanced growth of the embryo, and there is no means of supplying nourishment from the mother to the developing embryo. Hence the young, although they develop within the female's body, are born prematurely. Marsupials have a pouch with mammary glands, into which the newborn young climb.

An *opossum* is born a tiny, hairless creature about an inch long. From six to fifteen young are produced in one litter and a female usually bears two or three litters a year. The young stay in the pouch until they are large enough to leave, which is about two months. The opossum usually sleeps curled up in a tree through the day. At night it roams the countryside in search of small birds and mammals, eggs, and insects.

The *kangaroo* is a helpless, naked creature about an inch long at birth. It spends four months in the mother's pouch before venturing out. Even then it scampers back to the protection of the pouch when frightened.

Marsupials seem to have occurred over all the world during Cretaceous times. They became greatly reduced in the Cenozoic Era. Only in Australia are many species of marsupials successful today. Perhaps you will remember from your study of evolution in Chapter 13 that the reason for this is because of Australia's isolation as a continent. The more successful placental mammals never arrived to challenge the marsupials. As a result the marsupials evolved into various forms specialized for different ways of life.

At one time several marsupial forms were abundant in South America. But after South America became connected to North America, more suitably adapted mammals preyed upon the marsupials and successfully competed with them. Today oppossums are the only marsupials in the Western Hemisphere.

The placental mammals. The ***placental mammals*** are so named because a structure called the ***placenta*** (pla-*sent*-a) joins the mother's uterus to the embryo. The placenta permits oxygen and nutrients to pass from the mother to the developing embryo in exchange for the embryo's waste products. Thus the young of the placentals are born in a more advanced stage of development than the marsupials. In addition, evolution of a larger brain case and the development of various specialized kinds of teeth have contributed to the greater success of the placentals. Of the 28 orders of placental mammals that evolved during the Cenozoic Era, only 16 exist at the present time. We shall discuss 13 of these orders, which are listed on page 526.

38-3 The kangaroo is restricted in its native habitat to Australia. (Leavens-Photo Researchers, Inc.)

The insect-eating mammals. The ***insectivores,*** represented by the shrews and moles, were probably the first placental mammals. All of today's higher forms of mammals probably evolved from this order. The insectivores never became very large. Their brains are small and their teeth very primitive. The *shrew* is the smallest of all mammals, and resembles both a mole and a mouse. It is noted for its high metabolic rate, which gives it a ravenous appetite for insects, mice, and even other shrews. Shrews are seldom seen because they run along tunnels in the grass and hide easily under leaves. Such secretive habits have probably been responsible for the survival of shrews to the present.

The *mole* is well adapted for life under the ground. Its powerful limbs have long claws for digging, and the greatly reduced eyes are covered with skin. Its long nose is adapted for rooting out grubs and worms in the soil. While the mole is valuable in destroying many harmful beetle grubs, it is a pest in lawns and golf courses because it digs up the turf.

The flying mammals. The *bats* are classified in a different order from the insectivores, even though most of them eat insects. The ***chiropterans*** (ky-*rahp*-ter-anz) include more than 600 species of bats and vampires. These are the only mammals that have developed structures for flight. They have greatly lengthened finger bones covered by membranes. These structures probably evolved during the Eocene age, and there has been little change in the bats to modern times. Bats fly mostly at night when insects are abundant in the air. They spend the days hanging in a cave or hollow tree. They are nearly helpless on the ground because their hind limbs are so poorly developed and their forelimbs are proportionally so long. Bats are most numerous in the tropics, but they occur in all temperate zones as well. *Vampires* are members of this order that pierce the skin of cattle and other warm-blooded animals including man, and draw blood flowing from the wound.

The gnawing mammals. *Rats* and *mice* are among the most common ***rodents.*** Others include the *squirrel, woodchuck, prairie dog, chipmunk,* and *gopher.* The *beaver* is the largest North American rodent. The great value of beaver pelts brought the early trappers to the Northwest Territory. The *muskrat* is another fur-bearing rodent.

Rodents are doubtless the most successful group of mammals. They outnumber all other mammals combined, and are found in nearly every area of the world and in all climates. Most rodents are terrestrial, tree-living, or burrowing forms, but the beaver and muskrat have developed a semiaquatic existence, and the flying squirrel tends toward flight as it glides from tree to tree.

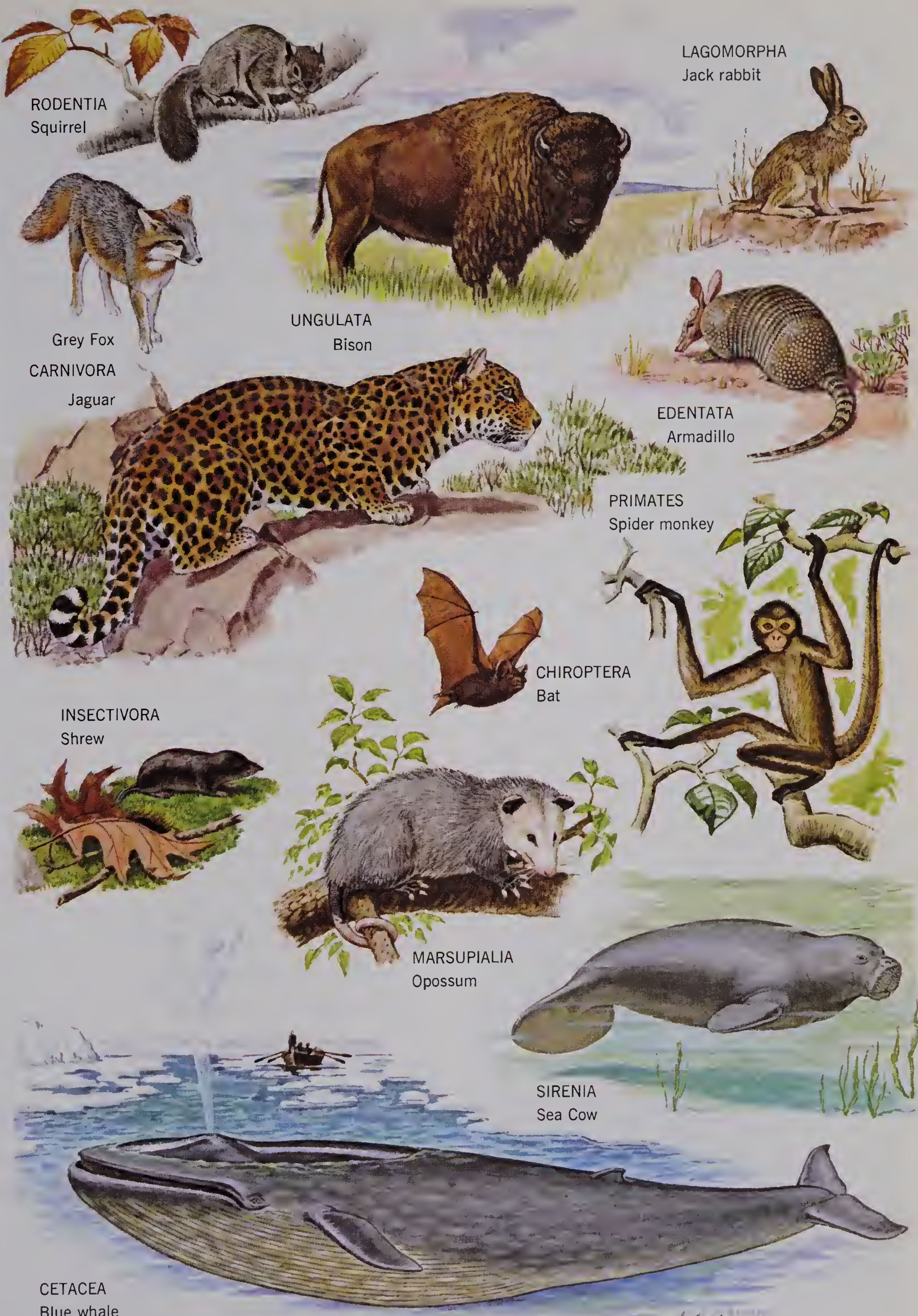
ORDERS OF MAMMALS

Order	*Representatives*
Monotremata (egg-laying forms)	Duckbilled platypus spiny anteater
Marsupialia (pouched forms)	Opossum, kangaroo
Insectivora (insect-eating forms)	Mole, shrew
Chiroptera (flying forms)	Bat
Rodentia (gnawing forms)	Squirrel, rat, beaver
Lagomorpha (rodentlike forms)	Rabbit, hare, pika
Edentata (toothless forms)	Armadillo, sloth
Cetacea (marine forms)	Whale, porpoise
Sirenia (aquatic mammals)	Sea cow
Proboscidea (trunk-nosed forms)	Elephant
Carnivora (flesh-eating forms)	Dog, cat, bear, walrus
Ungulata (hoofed forms)	Horse, rhinoceros goat, pig, deer
Primates (more or less erect forms)	Monkey, gorilla chimpanzee, man

38-4 Beavers show remarkable ingenuity in constructing dams and lodges. (McHugh from National Audubon Society)

Why have rodents been successful? Most of them are small, allowing them to live in environments not suitable to larger animals. They have a rapid rate of reproduction, which enables them to occupy new areas and adapt quickly to changing conditions. There is very little specialization in the body build. All have strong chisel-shaped teeth. These teeth have sharp edges that become even sharper with use because the front edge is harder than the back edge, causing the biting surface to wear at an angle. The forelimbs of rodents are adapted for running, climbing, and food-getting.

The rodentlike mammals. For many years biologists considered the rabbits, hares, and pikas to be rodents because they have enlarged incisor teeth for


RODENTIA
Squirrel
LAGOMORPHA
Jack rabbit
Grey Fox
UNGULATA
Bison
CARNIVORA
Jaguar
EDENTATA
Armadillo
PRIMATES
Spider monkey
CHIROPTERA
Bat
INSECTIVORA
Shrew
MARSUPIALIA
Opossum
SIRENIA
Sea Cow
CETACEA
Blue whale

38-5 These are examples of the eleven orders of mammals in the Western Hemisphere.

gnawing. These mammals, however, now called ***lagomorphs*** (*lag*-a-morfs), have four incisor teeth in each jaw rather than two as in rodents. They grind plant foods with a characteristic sideways motion of the lower jaw.

Pikas (*pie*-kaz) are small, with short legs and short ears. The *hares* and *rabbits* have long hind legs which enable them to leap great distances. The forelimbs are shorter and take up the shock of landing. The long ears give them an acute sense of hearing.

The cottontail rabbit is the most widely hunted mammal of the United States, and supplies more flesh than any other wild mammal. But even though preyed upon by man, predatory birds, and other animals, these rabbits have been able to hold their own in most localities. The jack rabbit is common in the broad expanses of the western prairies and plains. It reaches a length of nearly 30 inches and has characteristic long ears and large powerful hind legs. Both sight and hearing are especially keen, enabling it to escape from its enemies.

The toothless mammals. Sloths, armadillos, and great anteaters belong to an order of mammals that are toothless or nearly so. These ***edentates*** (ee-*den*-tayts) have relatively small brains and large claws, and some have nine neck vertebrae instead of the seven usually found in mammals. The *armadillos*, because of their protective armor, have survived since the Tertiary period. Their diet consists of insects, carrion, bird eggs, grubs, worms, birds, and other small animals. Various species of armadillo live in our southwestern states, Mexico, and Central and South America. Our North American species is known as the nine-banded armadillo. It hides in a burrow during the day and spends its nights digging in the ground for insects. The young of the armadillo are identical quadruplets. They start life as a single egg. Separation of cells early in development results in four individuals that ordinarily would have been one.

The *tree sloths* are odd beaverlike creatures of the jungles of Central and South America. They spend most of their time hanging upside down from the branches of trees by their greatly elongated limbs and hooked claws. They feed on the leaves of the trees in which they live. The hair of some species is colored green by the algae that live in it.

Anteaters probably evolved from the same ancestors as the tree sloths. The skull of the anteater is greatly elongated, ending in a long snout. Inside is a sticky tongue that can be extended to lap up the termites on which the animal lives. The greatly enlarged curved claws on their front feet are well adapted for digging in a termite's nest. Locomotion, however, is difficult. The animal walks and runs on the knuckles of its front feet. Anteaters and tree sloths are limited to tropical regions. Armadillos have spread northward into the temperate sections of North America.

The aquatic mammals. The ***cetaceans*** (si-*tay*-shunz) — the whales, dolphins, and porpoises apparently evolved from some land mammal during the Tertiary period. They are in many ways well adapted to life in the oceans. The torpedo-shaped body and fishlike tail and forelimbs provide for locomotion. These animals continue to use lungs for breathing, but they can take in great quantities of air and hold their breath for a long time. Thus they can

38-6 The cottontail rabbit is a very common North American animal. (U.S. Fish and Wildlife Service)

remain submerged for some time. The young are born with the ability to swim, and their mothers push them to the surface immediately for their first breath of air. Unlike man, they are able to withstand sudden changes in water pressure, and can dive to great depths.

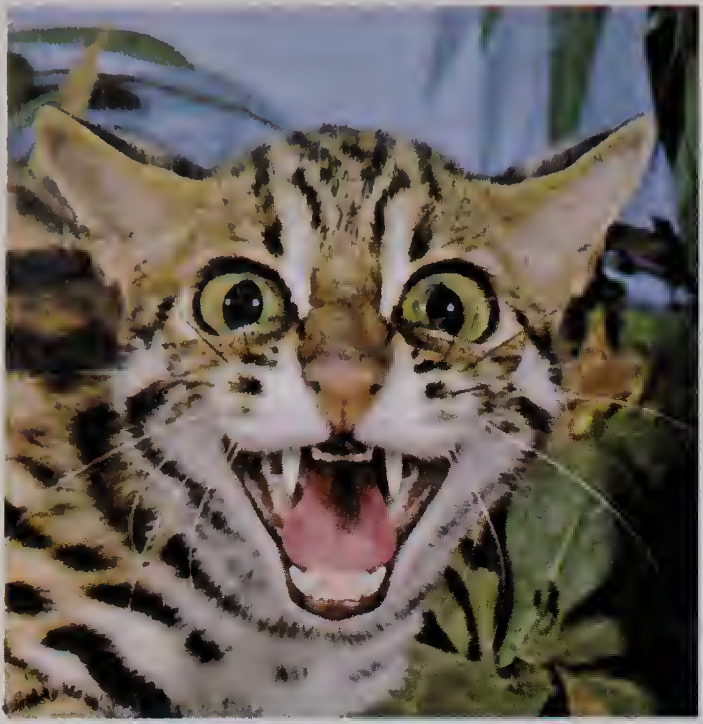
The *blue whale* is the largest living animal and probably the largest that ever lived. Specimens may reach a length of 100 feet or more and weigh as much as 150 tons. The head of the *sperm whale* contains an enormous reservoir of oil, which is used commercially as a lubricant and as a base for cosmetic creams. The most valuable product of this whale is ambergris, a secretion of the intestine. For centuries sailors have watched for ambergris floating on the ocean. Its principal use is in the manufacture of perfumes.

Dolphins are smaller relatives of the whale, usually under ten feet in length. They travel in herds in the ocean bays and mouths of rivers. Recent research in underwater sound has shown that dolphins communicate with one another. *Porpoises* also travel in herds, often close to moving ships, and delight the passengers with their graceful leaps. They feed on fish, which they catch in their narrow toothlined jaws.

The whales, porpoises, and dolphins are all strictly marine mammals; that is, they live only in salt water. Another order includes a mammal that lives in fresh water: the *sea cow*, or manatee, species of which inhabit the rivers of South America and Africa. These *sirenians* (sy-*ree*-nee-anz) probably became adapted for aquatic living during the Eocene period. Sea cows reach a weight of one ton. The large head resembles that of a walrus. The body is streamlined, and the hind limbs are lacking. The forelimbs of the sea cow are modified to form flippers, and they have a horizontal tail fin. Sea cows have a tough skin with a sparse covering

MARINE
STUDIOS

38-7 Porpoises may be more intelligent than we now realize. They seem to communicate with each other under water. (Annan Photo Features)



38-8 The enlarged canines of this leopard cat are typical of carnivores. (Van Nostrand from National Audubon Society)

of hair. They spend most of their time feeding on aquatic plants.

The trunk-nosed mammals. Only two species of elephants remain as representatives of the order of trunk-nosed mammals, or ***proboscideans*** (pro-*bahs*-sih-*dee*-anz). During glacial and preglacial times, at least 30 species of elephant-like mammals lived in Asia, Europe, Africa, and North America. The extinct proboscideans are the mammoths and mastodons. Biologists have not been able to explain why they became extinct.

Elephants are the largest of all living land dwellers. They may reach a weight of seven tons or more. The *Asiatic elephant* is the familiar performing elephant of the circus. In many parts of the world it is used as a beast of burden. The *African elephant* is a taller, more slender animal with a sloping forehead and enormous ears. African elephants travel in herds in the deepest parts of Africa and are not as easily domesticated as their Indian cousins.

The flesh-eating mammals. The flesh-eating mammals, or ***carnivores*** (*kahr*-ni-vorz), evolved in Tertiary times, probably from the insectivores. All of the carnivores have strong jaws with enlarged canine teeth for piercing tough skin and others for crushing bone. They have a high level of intelligence, which may enable them to outwit their prey. They have a well-developed sense of smell, and the sense of sight is usually keen. Powerful bodies and limbs and the presence of claws contribute to their ability to overcome and devour other animals. Variations in foot structure are used in dividing the order into families.

The dog and cat families are not as well represented in America as in other lands. The *puma* (*pyoo*-ma) [mountain lion or cougar] was found over most of North America at one time, but civilization has driven it to the remote regions of the southwest. Its chief harm lies in its destruction of livestock, especially young horses. Both the *bay lynx* (links), or bobcat, and the *Canada lynx* live in deep forests and are seldom seen. The *jaguars* of South America, the *lions* of Africa, and the *tigers* of Asia are all well-known members of the cat family.

The *gray wolf*, or timber wolf, is most frequently found in the northern forests and may be dangerous during the winter when it runs in packs. The *coyote* (*ky*-oht), a prairie wolf, has been more successful than its larger cousin in surviving the effects of civilization. It is still abundant on the western plains. However, in some regions too many have been destroyed and their natural prey, including rodents and jack rabbits, have become pests. It has therefore been necessary to import coyotes into these regions.

The *red fox,* together with the other foxes that are color phases of the red fox, ranges over much of the United States. It is sly and a very fast runner for short distances. The gray fox resembles the red fox but lives in the warmer regions of the South.

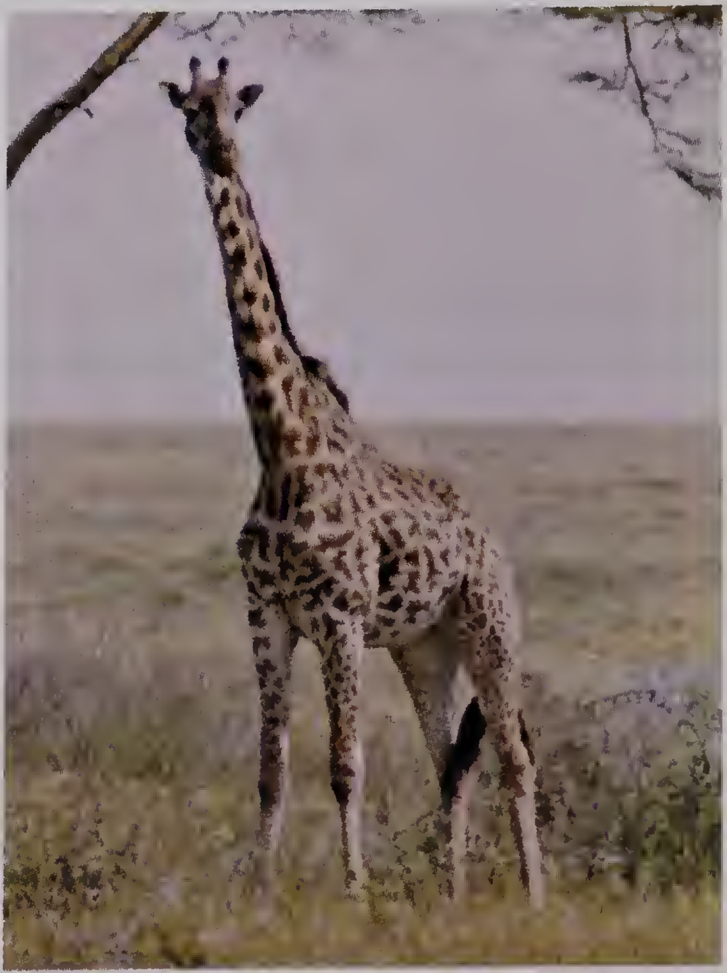
The *raccoon,* with its black mask and long-ringed tail, is a favorite of many people because, if captured young, it makes a nice pet. The raccoon prefers fish and clams as its food but will eat other things as well if these are unavailable. It has a habit of washing its food before eating. This is probably to moisten the food rather than to clean it.

The weasel family includes some of the most blood-thirsty carnivores and some of the most valuable fur-bearing mammals. The *mink* especially is prized for its fur. These long-bodied, short-legged animals live along streams. The *ermine* is an Arctic weasel which grows a coat of white fur (except for a black-tipped tail) in winter but is brown in summer. The largest and most destructive member of the family is the *wolverine* of the northern forest. Its body, including its bushy tail, is about 36 inches long and weighs between 30 and 35 pounds.

The *bears* were the last carnivores to evolve, but they have changed little since Pleistocene times. Bears have teeth specialized for eating plant substances as well as meat. The molar teeth are elongated and the enamel of the crown is wrinkled. Bears are widely distributed, but are not found in Africa or Australia.

Sea lions, walruses, and *seals* are water-living carnivores. Their bodies are streamlined for swimming, but they have never developed the finlike appendages of whales and dolphins. They have webbed feet, the front ones serving for balance and stability, and the rear ones turned in such a way as to provide an efficient means of propulsion. Walruses probably evolved from sea lion ancestors. Their canine teeth have become long tusks, and they have developed broad molars to facilitate crushing and grinding the oysters and other mollusks on which they feed.

The hoofed mammals. Man has lived in close association with the hoofed mammals, or ***ungulates*** (*un*-gya-layts), since prehistoric times. The goat was probably the first to be domesticated. For ages man has depended on the horse, camel, ox, llama, and other hoofed mammals as beasts of burden. The cow, pig, and sheep are our principal food animals. Deer, elk, caribou, moose, and antelope are our most important big game ungulates.



38-9 The giraffe, a cud-chewing ungulate, is the tallest living four-footed animal. Its elongated limbs are well adapted for swift running. (Boker from National Audubon Society)

The teeth of these animals have become adapted to cropping and grinding grasses, leaves, and stems, as they are all herbivores, or plant eaters. Some of the hoofed mammals have elongated limbs and feet that enable them to cover hard ground rapidly. They frequently walk on the tips of their toes, with the wrist and ankle off the ground. Hoofs, which are modified toenails, help to absorb the shock of running.

About sixteen families of ungulates evolved, probably from the insectivores, in the Cenozoic Era. Biologists classify the hoofed mammals as to whether they have an even number of toes or an odd number. Of the odd-toed ungulates, only the *horses* continue to flourish, although the *tapir* and *rhinoceros* are also odd-toed. The even-toed forms have become very numerous and are probably at their peak today. These include the *pig* and *hippopotamus*, and the cud-chewers, or ***ruminants*** (*roo*-mi-nants). The *cow, ox, bison, sheep, goat, antelope, camel, llama, giraffe, deer, elk, caribou,* and *moose* are all ruminants. These animals have four-chambered stomachs. While grazing, they eat large quantities of food, which passes into a large paunch, or ***rumen***, the first of the stomach divisions. Here food is stored for later chewing. Later the food is forced back into the mouth for leisurely chewing as a cud. After thorough chewing, the cud is swallowed into the second stomach, where digestion begins. From there it passes through the other stomach regions to the intestine.

The erect mammals. Superior brain development places the ***primates***, or erect mammals, at the top of all groups of living organisms. Primates have well-developed arms and hands. Their fingers are used for grasping, and one or more fingers or toes are equipped with nails. Most primates can walk erect if necessary. Primates live in South America, Africa, or the warm regions of Asia. They tend to be tree-living, with man the only one living exclusively on the ground. The teeth of the primates are less specialized than in any group of mammals. They feed on plants and flesh. Eyesight is well developed in the primates, but the sense of smell is poorly developed.

The apes are most like man in body structure. They have no tails. The arms are longer than the legs. When walking, the feet tend to turn in. These primates, especially the chimpanzee, respond to a very high degree of training. They include the following:

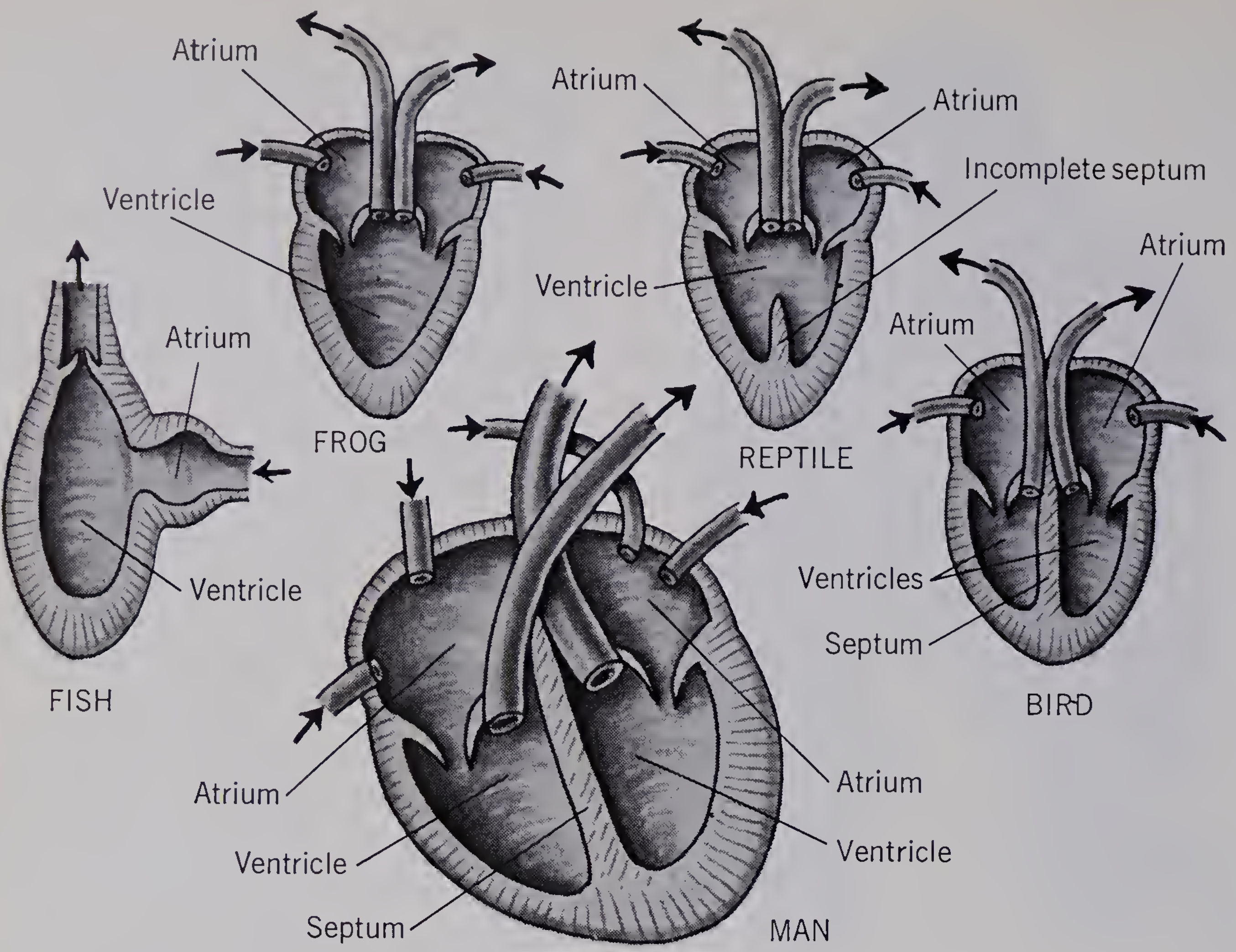
1. The *gorilla*, the largest of the apes, lives in Africa. It walks on two feet and is one of the most powerful animals.
2. The *chimpanzee* also lives in Africa. It is smaller than the gorilla and quite intelligent.
3. The *orangutan* lives in the East Indies. It is a droll animal with red hair.
4. The *gibbon* is a long-armed type found in Asia.
5. The *Old World monkeys* have long tails but do not use them in climbing. They sit erect. Food is stored in cheek pouches. The baboon, an Old World monkey, has a long, dog-like nose.
6. *New World monkeys* have flat, long tails used for grasping. The septum between the nostrils is wide, and these monkeys lack cheek pouches.
7. *Marmosets* are small primates ranging from Central America to South America. They resemble squirrels in appearance and activity.
8. *Lemurs* are primates found in Madagascar.

38-10 Primates are interesting mammals because of their ability to grasp objects and to walk on two feet if necessary. (New York Zoological Society)

Diversity among the mammals. In your survey of mammalian orders, you undoubtedly noticed the diverse lines along which mammals have developed. Many adaptations have occurred in the limbs, especially the forelimbs. We found limbs for digging, hanging, flying, running, defense, and capturing prey. These limb modifications have equipped mammals for life in nearly all the environments of the earth. Their numbers compete successfully with the fish in aquatic environments, amphibians and reptiles on land, and with the birds in the treetops.

Variations in tooth structure are nearly as pronounced as those of limbs. Well-developed incisors serve as chisels in the mouths of rodents. Greatly enlarged canine teeth form the flesh-tearing fangs of cats and dogs and other carnivores. Large molars provide the grinding surfaces for grazing animals like the deer, the cow, and the horse. These modifications and others, including antlers and horns, and protective coloration provided by pigmented hair which blends with the environment, are of great importance in the distribution of mammals. However, to find the reason for the supremacy of mammals, we need to take a closer look at the mammal's internal development.

Regulations of the internal environment. In the body of the mammal we find tissue specialization and organ development at the most complex level in all of life. With this specialization, however, comes increasing cell dependence. Mammals could never have reached their high level of development without a controlled internal environment. We refer to mammals as well as birds as warm-blooded vertebrates. Except during periods of hibernation or inactivity the body temperature remains at a nearly constant level. The maintenance of this uniform internal temperature requires the combined activity of many highly developed organs and organ systems. We might begin with the release of heat during respiration in the tissues. Here we find the rate of cell metabolism elevated far above that of the cold-blooded vertebrates whose body temperature fluctuates with that of the environment. Increase in the metabolic rate requires an increase in the supply of nutrients and oxygen to the cells. Highly efficient digestive organs and well-developed lungs are necessary to supply these needs. The increased rate of metabolism results in more metabolic wastes which must be removed from the cells constantly. Supply and waste removal


Atrium
Ventricle
FISH
Atrium
Ventricle
FROG
Atrium
Atrium
Incomplete septum
Ventricle
REPTILE
Atrium
Atrium
Ventricles
Septum
BIRD
Atrium
Ventricle
Septum
Atrium
Ventricle
MAN

38-11 Comparative heart structure of the vertebrate classes. Notice the development from two to four chambers.

for billions of cells composing the body of a mammal require an extensive transport system and a powerful heart to force blood through its many miles of vessels. Kidneys which surpass those of all other animals in functional efficiency remove the waste products of cell metabolism in a complicated system of blood filters.

We find the basis for mammalian structure and function in the lower vertebrates you have studied. In fact, we can trace the development of each organ system through stages represented in these lower forms.

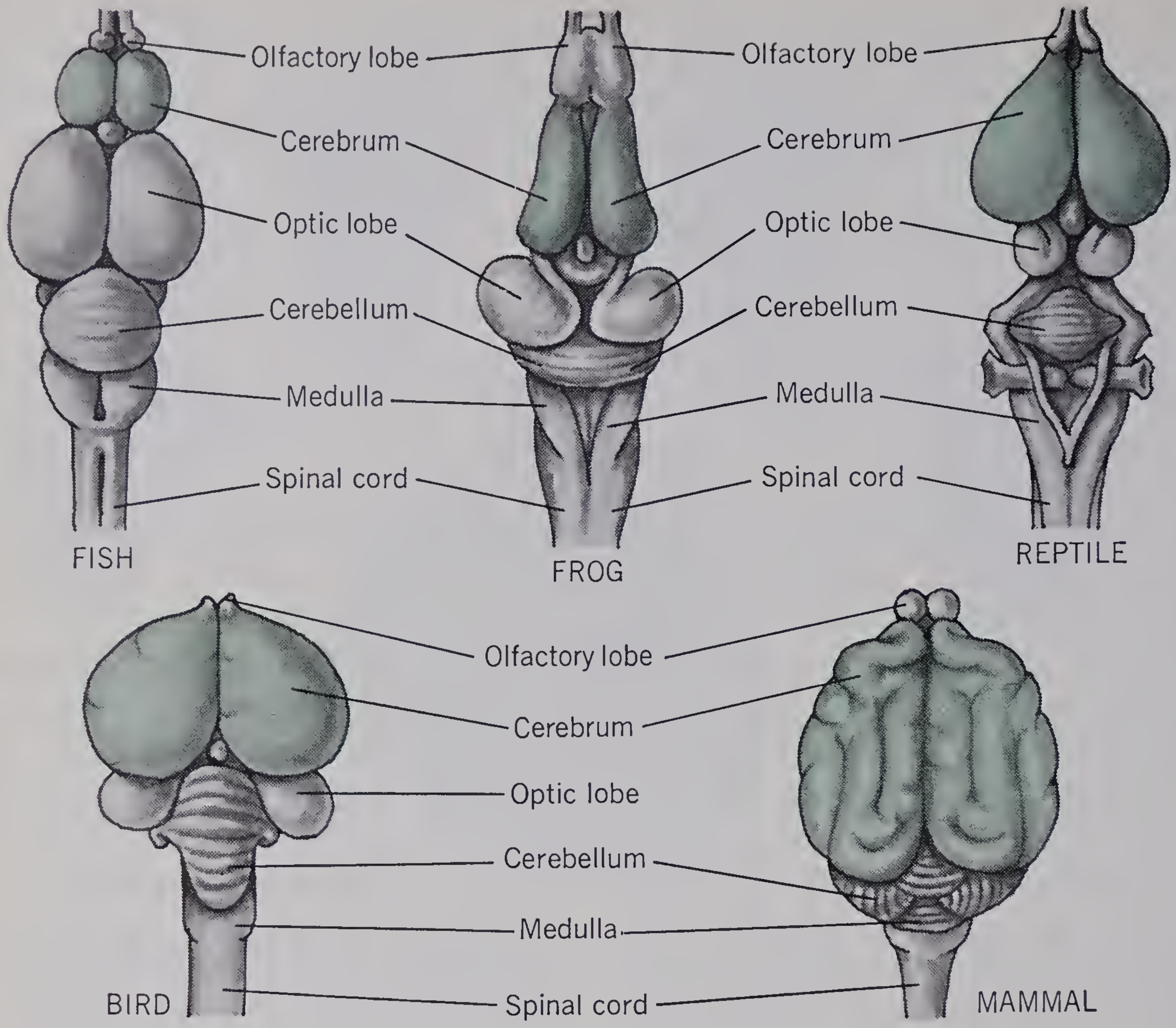
Development of heart and lungs of a mammal. In many ways the efficiency of the transport system is the key to the development of warm-blooded animals and regulation of the internal environment. However, in considering the heart and circulatory system of the mammal we must also include the organs of respiration, for these two systems are closely related. Let us think back to the fish. Here a relatively small heart composed of two chambers is sufficient to force blood through a circulatory system consisting of a single circuit. One ventricle provides sufficient pressure to force blood through the gills and to the vessels of the body without returning to the heart between the two circulations. Gills are relatively simple organs of respiration which function efficiently in a water environment. Since the metabolic rate of a fish is much below that of the higher vertebrates and varies with the water temperature, a two-chambered heart is adequate. However, neither gills nor two-chambered hearts are suitable for life on land.

In the amphibians, especially in the adult stages of frogs, toads, and salamanders, the heart has undergone a structural change which permits life in a land environment. Here we find a separation of the upper heart chambers into two atria. The presence of these two chambers provides separation of deoxygenated blood from the body from oxygenated blood from the lungs. However, mixing occurs in the single ventricle which forces blood to the body tissues as well as to the respiratory organs. Such a heart could not supply the requirements of a bird or a mammal. For one thing, the pumping of mixed blood to the body tissue could not supply the oxygen requirement of the mammal. Furthermore, the lungs of amphibians are not adequate to supply the needs of a bird or a mammal. Remember that amphibians still require skin respiration. This function of the skin has been lost in the bird and mammal with increase in thickness and development of the body covering.

The reptile heart is still more efficient than that of the amphibian because the ventricle is partially divided by a partition, or septum. The mammalian heart, like that of a bird, eliminates all mixing of blood because of a complete septum forming two separate ventricles. Thus it is really a double pump. The right side receives the deoxygenated blood from the body and pumps it to the lungs, and the left side receives oxygenated blood from the lungs and forces it throughout the entire body.

Development of the nervous system. The high degree of development and specialization of the nervous system is the primary factor that has placed the mammals above all other forms of life. The brain of the mammal is larger, in proportion to the body weight, than that of any other animal. This high development of the mammalian nervous system could have occurred only in a closely regulated internal environment. Of all the body tissues, nerve tissue is probably the most dependent and the most rapidly affected by internal changes.

We can learn a great deal about the behavior and mental abilities of the vertebrates by comparing their brain structure. The brain of the most primitive vertebrates consists of three main regions: a *forebrain* composed of the olfactory lobes, or bulbs, and the two hemispheres of the cerebrum; the *midbrain* containing the optic lobes; and the *hindbrain* composed of the cerebellum and medulla. All vertebrates have these brain regions, but their relative size varies (Fig. 38–12). When we compare the brain structure of the various vertebrates, we see an evolutionary pattern in which the relative size of the cerebrum increases and reaches its highest development in the mammal. You will recall from your studies of the brain of the fish that the cerebral hemispheres are relatively small. Large olfactory lobes extend from the anterior region of the cerebrum, indicating that the sense of smell is well developed in the fish. The largest brain regions in the fish are the optic lobes. In the amphibian the cerebral hemispheres are proportionally larger. This increase in the relative size of the cerebrum continues in the reptiles and also in the birds.


Olfactory lobe
Cerebrum
Optic lobe
Cerebellum
Medulla
Spinal cord
FISH
Olfactory lobe
Cerebrum
Optic lobe
Cerebellum
Medulla
Spinal cord
FROG
REPTILE
Olfactory lobe
Cerebrum
Optic lobe
Cerebellum
Medulla
Spinal cord
BIRD
MAMMAL

38-12 Note the size of the cerebrum in the mammalian brain as compared with that of the fish, frog, reptile, and bird.

It is interesting that various vertebrates differ also in the relative sizes of the cerebellum. This brain area functions in muscle coordination. The cerebellum is relatively large in most fish but is greatly reduced in amphibians. In the birds and mammals it is large and well developed.

In the mammalian brain the cerebral hemisphere fills most of the cranial cavity and is spread over the other brain regions. The olfactory area consists of two lobes extending from the anterior regions on the lower side of the cerebrum. The optic region lies in the posterior region of the cerebral hemisphere. The cerebellum lies below and posterior to the cerebrum. The high development of this brain region accounts for the excellent muscle coordination of the mammal. The short medulla oblongata, which controls vital body processes, lies below the cerebrum and extends to the spinal cord. Cranial nerves extend from the brain to the sense organs and other head structures. The spinal nerves extend from the spinal cord to and from all regions of the body.

Mammalian reproduction. Another line of development that has occurred in the vertebrates has been an increase in the efficiency of reproduction and a corresponding decrease in the number of young. Let us return to a consideration of the fish, where species are preserved only because of the enormous number of eggs produced. Depending on the species, a fish may lay from a few hundred to several million eggs. You will recall that fertilization is external. The male fish swims over the eggs and discharges milt containing sperm. Many eggs are never fertilized. Many are eaten before they hatch. In most fishes the young are given little or no parental care when they are hatched. As a result, most of the young fall victim to predators before reaching maturity.

Amphibians lay smaller numbers of eggs which are fertilized directly as they are laid. This insures the development of a much greater proportion of the eggs laid. As in the fish, however, amphibians must deposit eggs in water, since they have no protection against drying out

An abrupt change occurs in the reptiles, the first vertebrates to lay eggs on land. This advance requires internal fertilization and the enclosure of the egg with protective shells. Similar eggs are produced by birds. With the greater protection supplied by the eggs of reptiles and birds, the number is greatly reduced. Parental care, especially among the birds, reduces the mortality rate of offspring greatly.

In all mammals but the monotremes, development is internal. As you learned in your study of marsupials, the young are born prematurely. However, the pouch on the underside of the female provides a protective "incubator" where development may continue. The mammary glands open into the brood pouch and provide the young with nourishment.

In the placental mammals, following internal fertilization, the developing embryo attaches and embeds in the wall of the uterus. Specialized tissues composing the placenta exchange nutrients, oxygen, and waste products between the embryo and the mother. Thus, the developing placental mammal benefits from the functions of the organs of the female. As a result, the mammal may develop longer and reach a larger size before birth occurs.

The period between fertilization and birth is called the ***gestation period.*** The following table of gestation periods shows the variation in intervals between fertilization of the egg and birth among various mammals.

Parental care. The fact that a young mammal is nearly helpless and dependent on its mother's milk for a time after birth makes parental care necessary. Male mammals are not usually involved in the care of the young. Parental care requires that the number of young be smaller among mammals. This number is usually proportionate to the length of parental care. Mice, rabbits,

GESTATION PERIODS

Mammal	*Period*	*Mammal*	*Period*
Opossum	13 days	Human	40 weeks
Mouse	21 days	Cow	41 weeks
Rabbit	30 days	Horse	48 weeks
Cat	63 days	Whale	20 months
Dog	63 days	Elephant	20 to 22 months
Pig	120 days		

and other small mammals bear several litters, often numbering ten or more each season. However, there are many predators that feed on these mammals and their chance of survival is not as great as that of larger mammals. Larger mammals produce smaller numbers of young and provide parental care over a longer period.

Mammals vary greatly in their degree of development at birth. Mice and rats are born hairless and blind. A baby bear weighs less than a pound when it is born during winter hibernation. On the other hand, a cow, horse, deer, or bison is born in a much more advanced condition and can stand and walk with the mother a few hours after birth. The young whale is born in a well-developed condition after a long gestation period. The newborn porpoise is half as long as its mother.

Of all the mammals, the human is the most helpless at birth and requires the greatest parental care for the longest period of time. Much of this time is devoted to training in which the child is learning to walk, talk, think, and reason.

IN CONCLUSION

With the mammals, we have reached the peak of vertebrate development. With their diverse adaptations, regulated internal environment, highly specialized internal organs, and high level behavior made possible by a superior brain, mammals have evolved as the most successful land animals. Since life on the earth began, organisms at various stations of development have had their period of prominence. We speak of an age of invertebrates, an age of fishes, an age of amphibians, and an age of reptiles. The age in which we live might be called the age of mammals.

The next unit will present a more thorough study of mammalian anatomy, physiology, and behavior. The subject will probably be the most interesting of all to you — the human body.

BIOLOGICALLY SPEAKING

carnivore
cetacean
chiropteran
edentate
gestation period
insectivore
lagomorph
mammary gland
marsupial
monotreme
placenta
placental mammal
primate
proboscidean
rodent
sirenian
ungulate

QUESTIONS FOR REVIEW

1. List several early mammals that are now extinct.
2. According to biologists, which North American mammal is most ancient?
3. List ten characteristics of mammals that distinguish them from other vertebrates.
4. In what way are the duckbilled platypus and spiny anteater different from all other mammals?

5. What characteristics of marsupials distinguish them from placental mammals?
6. Lagomorphs are similar to rodents. How may they be distinguished on the basis of tooth structure?
7. In what respect is the armadillo an exception to the rule in the body covering of mammals?
8. Describe adaptations of the cetaceans for life in the sea.
9. Name two elephants that have become extinct since glacial times.
10. List several North American carnivores.
11. Describe various adaptations of the hoofed mammals.
12. On what basis might we consider the primates the most highly developed mammals?
13. What is the biological meaning of "warm-blooded?"
14. What other class of vertebrates is most like the mammals in heart structure?
15. Which region is most highly developed in the mammalian brain?
16. Why must the young of marsupials spend the early part of their lives in a brood pouch?
17. In what way is the number of young related to parental care?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the relation of the regulated internal environment to the biological development of the mammal.
2. Compare the structure and functional efficiency of the mammalian heart with the hearts of other vertebrates.
3. Account for the high level of behavior of the mammal in terms of brain structure and development.
4. What characteristics of mammalian reproduction give these animals an advantage over other vertebrates?

RELATED READING

Books

Austin, Oliver. *Birds of the World.* Golden Press, New York. 1961

Barker, Will. *Familiar Animals of America.* Harper and Row, New York. 1956

Bates, Marston. *Animal Worlds.* Random House, Inc., New York. 1964

Breland, Osmond P. *Animal Life and Lore.* Harper and Row, New York. 1964

Carr, Archie. *The Reptiles.* Time, Inc., New York. 1964

Carrington, Richard and Editors of Life. *The Mammals.* Time, Inc., New York. 1964

Crompton, John. *Snake Lore.* Doubleday and Co., Inc., Garden City, N. Y. 1964

Detheir, V. and Stellar, E. *Animal Behavior.* Prentice-Hall, Inc., Englewood Cliffs, N. J. 1961

Ditmars, Raymond L. *The Reptiles of North America.* Doubleday and Co., Garden City, N. Y. 1936

Earle, Olive L. *Birds and Their Nests.* Wm. Morrow and Co., Inc., New York. 1952

Eaton, Theodore. *Comparative Anatomy of the Vertebrates.* Harper and Row, New York. 1960

Guyer, Michael F. and Lane, Charles E. *Animal Biology.* Harper and Row, New York. 1964

Halstead, Bruce W. *Dangerous Marine Animals.* Cornell Maritime Press, Cambridge, Md. 1959

Hylander, Clarence J. *Fishes and Their Ways.* The Macmillan Co., New York. 1964

Kohn, Bernice. *Marvellous Mammals: Monotremes and Marsupials.* Prentice-Hall, Inc., Englewood Cliffs, N. J. 1964

La Gorce, John Oliver, Ed. *The Book of Fishes*, Rev. Ed. National Geographic Society, Washington. 1952

Lanyon, Wesley E. *Biology of Birds.* The Natural History Press, Doubleday and Co., Garden City, N. Y. 1964

Life Nature Library. *The Fishes.* Time, Inc., New York. 1963

Mayr, Ernst. *Animals Species and Evolution.* Harvard University Press, Cambridge, Mass. 1964

National Geographic Society. *Wild Animals of North America.* The Society, Washington, D. C. 1960

Norman, J. R. *A History of Fishes*, 5th Ed. Hill and Wang, New York. 1960

Parker, H. W. *Snakes.* W. W. Norton and Co., Inc., New York. 1964

Peterson, Roger Tory and Editors of Life. *The Birds.* Time-Life Books, Chicago. 1964

Pope, Clifford H. *The Giant Snakes.* Alfred A. Knopf, Inc., New York. 1961

Raskin, Edith. *Watchers, Pursuers and Masqueraders: Animals and Their Vision.* McGraw-Hill Book Co., Inc., New York. 1964

Romer, Alfred S. *The Vertebrate Story*, 4th Ed. University of Chicago Press, Chicago. 1959

Scheele, William E. *Prehistoric Animals.* The World Publishing Co., Cleveland. 1954

Smyth, H. *Amphibians and Their Ways.* The Macmillan Co., Chicago. 1962

Articles

Ayotte, A. E. "The Last Stand of the Alligators." *Audubon Magazine.* July-August, 1964

Cone, Clarence, D., Jr. "The Soaring Flight of Birds." *Scientific American.* April, 1962

Frieden, Earl. "The Chemistry of Amphibian Metamorphosis." *Scientific American.* November, 1963.

Gilbert, Perry W. "The Behavior of Sharks." *Scientific American.* July, 1962

Heald, Weldon F. "Snakes Are Interesting." *Audubon Magazine.* July-August, 1964

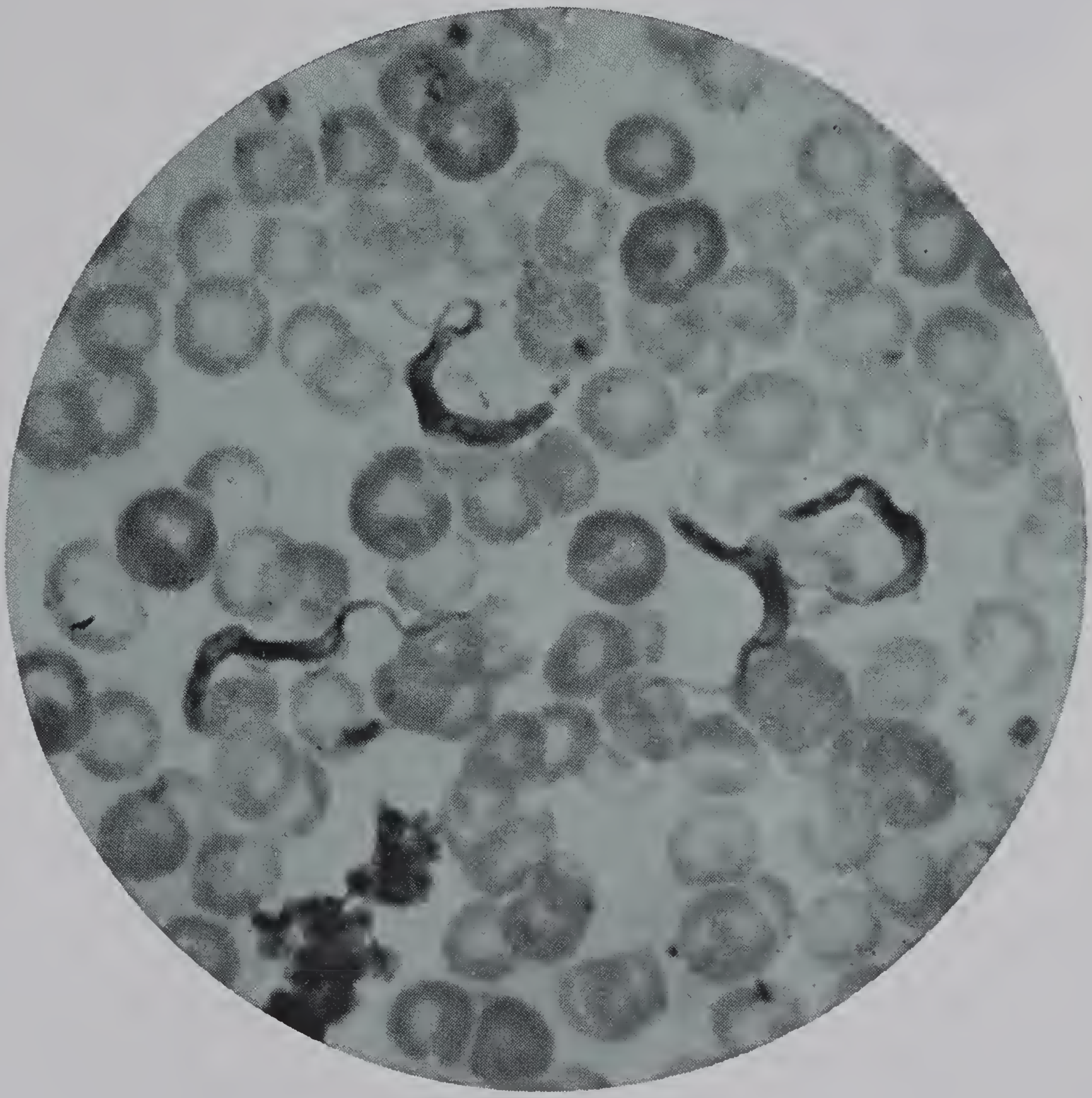
Kortlant, Adriaan. "Chimpanzees in the Wild." *Scientific American.* May, 1962

Muntz, W. R. A. "Vision in Frogs." *Scientific American.* May, 1962

Shaw, Evelyn. "The Schooling of Fishes." *Scientific American.* June, 1962

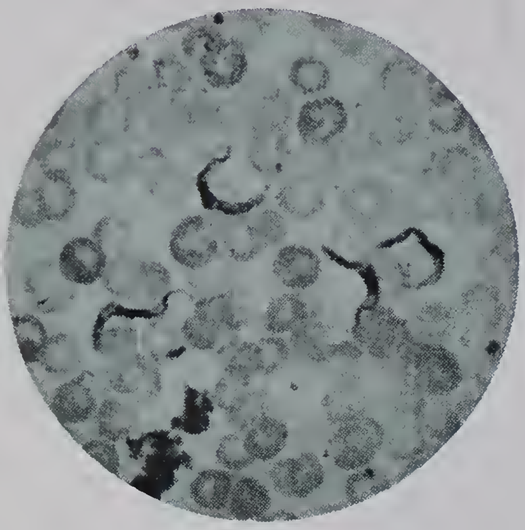
UNIT SEVEN

THE BIOLOGY OF MAN



Having followed the development of organs and organ systems through increasing levels of advancement and efficiency in the vertebrate classes, it is fitting that our study of anatomy, physiology, and body chemistry concern the mammal. What better example to use than the human body? Man, the most advanced living organism, dominates the living world. Intelligence, ingenuity, and creative ability have made him the master of every environment on the earth and in space beyond.

CHAPTER 39



THE HISTORY OF MAN

Man and mammals. The organs and systems of the human body closely resemble those of other mammals. The structural similarity of man and the other primates is especially striking. Almost every anatomical detail is similar. You can observe this similarity in the skeleton and muscles, tooth structure, position and structure of the eyes, form of the hands and feet, and even in the facial expressions. Similarities in the internal structures of man and the other primates are equally striking. They may be seen in the structure of the heart and blood vessels, lungs, digestive organs, excretory organs, glands, and nearly all other internal organs.

Even the chemical secretions of man and other mammals are similar, and the digestive enzymes are the same. The insulin used to save the lives of diabetics is extracted from beef or hog pancreas. The Rh factor, so important in matching human blood types, was discovered originally in the blood of the Rhesus monkey.

Although man is structurally and biochemically similar to the other mammals, he has significant differences that have allowed him to become biologically superior. He is the only mammal with truly upright posture. This is possible because he has a shortened and flattened pelvis which holds the abdominal organs. The upright posture freed man's hands so that they could be used entirely for manipulation. At the same time the action of man's thumb opposes that of the fingers, so that his hand is ideally suited for grasping. Because of their many sensory receptors, the hands are highly sensitive to touch and are grooved so that they can grip smooth objects.

Both of man's eyes see the same vision from slightly different angles, resulting in an improved sense of depth. The combination of intelligence, acute vision, and efficient hands is ideal for the use of tools, an ability peculiar to man. The characteristic that has probably made the most difference in man's development, however, is his capacity to use symbols in the form of the written and spoken word. This ability to communicate with others of the same species by symbols and to pass learning on from generation to generation has allowed man to undergo a rapid cultural evolution not possible in other species.

Theories about man's development. In 1871 the English biologist Charles Darwin published his famous book entitled *The Descent of Man.* Darwin proposed that the same forces operating to bring about changes in plants and animals could also affect man and his development. Biologists classify man as a primate because of his many structural similarities to the monkey, gorilla, chimpanzee, orangutan, and gibbon. In his book, Darwin pointed out these similarities, and some people interpreted his comparisons as suggesting that man evolved from monkeys. Actually this unfortunate misinterpretation was far from Darwin's intent. As you know, it is the less specialized primitive forms that are most able to move into new environments and evolve into new species. The orangutans and chimpanzees of today are highly specialized forms that have probably evolved from more primitive ancestors. Likewise, modern man has probably evolved from primitive, more generalized ancestors. If we were able to trace the history of the primates back perhaps ten million years, we might find a generalized primate that was common ancestor to both modern man and the modern primates. It is most likely, however, that the two lines of descent separated at a very early date and gradually evolved into the forms of today.

At the time Darwin lived, no remains of early man had been found. Since then hundreds of bones have been unearthed. They have been dated and studied by ***anthropologists***, who specialize in the history of man. This evidence still does not provide us with a complete picture of man's development, but the fossils serve as clues from which hypotheses can be formed. A fossil skull indicates the size of the brain, shape of the head, and age of the man at the time of death. The jaw structure indicates whether its owner had the capacity for speech. It would not mean, however, that a language was used.

A study of the environment of primitive man also helps to piece together man's development. What did early men eat? Wherever the anthropologist finds evidences of primitive man, he searches for fossil remains of animals that might have been used for food. Charred bones indicate that he had learned to use fire to cook meat. The type of food also indicates the climate and nature of the surroundings. The anthropologist is also interested in evidence of tools, since their use is unique to man. If similar tools are found over a wide area, some type of communication must have occurred. The material used and the complexity of the tools are indications of how highly developed the men were.

How fossils are dated. In Chapter 13 we discussed the dating of fossils by the determination of the relative ages of the layers of the earth. The ***radiocarbon method*** is also used to date fossils. This method was made possible by the discovery in 1930 of a radioactive isotope of carbon with an atomic weight of 14 instead of 12. In living organisms there is about one carbon-14 atom to one trillion carbon-12 atoms.

Radioactive isotopes spontaneously give off radiations at a constant rate, changing eventually to the stable form of the element. The time required for half of a sample of a radioactive isotope to decay to the stable form is called the ***half-life***. The half-life of carbon-14 is 5,568 years.

As long as an organism is living it incorporates carbon compounds into its body, but at death this process ceases. Thus, if a sample of bone is examined and found to contain half the amount of carbon-14 that occurs in organisms today, its age would be estimated at 5,568 years. The radiocarbon method is considered to be accurate to about 50,000 years.

Recently another method of dating has been developed. Similar to the carbon-14 technique, the ***potassium-argon method*** depends on the fact that potassium-40 breaks down into calcium-40 and argon-40 at a slow but constant rate. This method has its shortcomings because it involves the presence of argon-40 in a rock sample. In dating a fossil by this method, a rock that was formed at the same time the organism was alive has to be found.

Putting together the pieces. In 1924 a perceptive worker in a South African quarry noticed a small fossilized skull that had been dislodged by blasting. When the fossil was given to a South African medical school, Professor Raymond Dart, an anatomist, recognized its resemblance to human skulls. Dr. Dart named the primate ***Australopithecus*** (au-*stray*-lo-pith-i-kus) ***africanus,*** which means "southern ape from Africa." Since then other bones of this primate have been found.

Dr. and Mrs. L. S. B. Leakey have spent nearly 35 years excavating and studying fossils. Much of their effort has been near the Olduvai Gorge in Tanganyika, now Tanzania. They first found many pebble tools thought to have been used for cutting instruments. In 1959 the Leakeys unearthed some teeth, which led to the excavation of an area believed to be a campsite of ancient man. Since then, skull fragments have been pieced together. Bones from a foot, fingers, and a lower jaw with well preserved teeth have provided us with clues about the structure of the primate that was named ***Zinjanthropus*** (zin-*jan*-thro-pus). By using the potassium-argon method, scientists at the University of California have placed its age at 1,750,000 years.

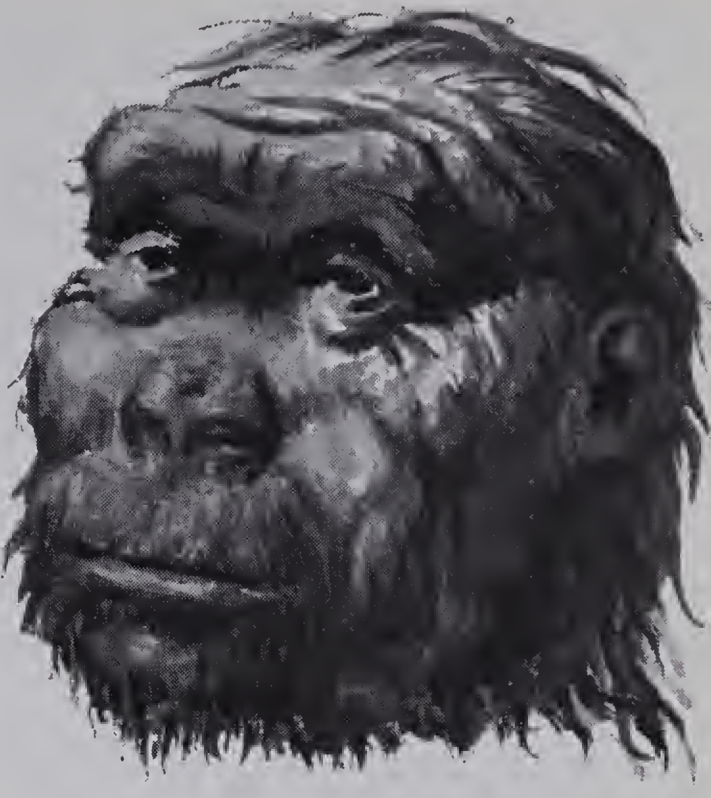
39-1 Dr. L. S. B. Leakey, the eminent British anthropologist who unearthed the remains of the earth's earliest known manlike creature in East Africa, examines the skull of his 1,750,000-year-old discovery. (© National Geographic Society)

The bones of *Zinjanthropus* and *Australopithecus* are similar and look like those of modern apes. The pointed fanglike teeth of modern apes are not found in these forms, however. Also, the shape of the pelvis and opening for the spinal cord in the skull indicate an upright posture. Anthropologists are not agreed as to whether these forms should be placed in the ape family or in the family that includes man.

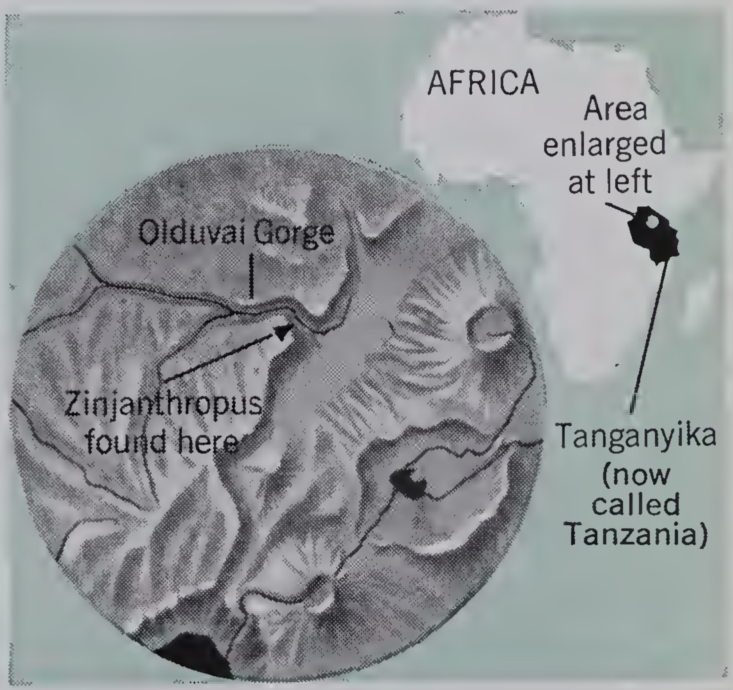
In mid-1964 Dr. Leakey published an account of the discovery of the remains of still another primitive manlike form in the Olduvai Gorge. He has named this form ***Homo habilis,*** and dating evidence indicates that it lived at the same time as *Zinjanthropus*. *Homo habilis,* however, is more manlike. He seems to have walked and run erect, to have had a well opposed thumb, and to have eaten both meat and plant foods, like modern man. Dr. Leakey now believes that *Homo habilis* was the ancestor of modern man, while *Zinjanthropus* and *Australophithecus* were evolutionary dead ends. Dr. Leakey's theory indicates that the genus Homo was present on earth about 1,200,000 years earlier than anthropologists had previously thought.

Early forms of man. In 1891 a part of a skull, a piece of a jaw, and an upper leg bone were discovered in an excavation on the island of Java. These remains lay in a deposit of sand and gravel transported by an early glacier, so that the period could be roughly dated. Similar remains were found in the same general region in 1937. Java man, as he was first called, is believed to have walked erect, so that he is now called ***Pithecanthropus erectus.*** He is thought to have lived 500,000 years ago. He had a slanting forehead and heavy brow ridges. The skull of Java man indicates that his brain, while only about half the size of modern man's, was more than one third larger than that of the present-day gorilla. Anthropologists believe that Java man learned to make use of crude stone weapons and of fire. *Pithecanthropus* remains have also been discovered in excavations of ancient caves near Peking. Many of the skulls of Peking man that were found are broken near the base, suggesting he was a head hunter.

Neanderthal man. More is known about ***Neanderthal*** (nee-*an*-der-thol) ***man,*** who lived in Europe, Asia Minor, Siberia, and Northern Africa. Scientists believe that Neanderthal man disappeared about 25,000 years ago, near the close of the glacial age. Information about him has been acquired from careful study of almost 100 skeletons, many of them nearly complete. He was about five feet tall and walked in a stooped position. His bone structure indicates that he was powerfully built. His facial features were coarse. Like *Pithecanthropus,* his forehead sloped backward from heavy brow ridges. His mouth was large, and he had little chin.



39-2 Above: a drawing showing how *Zinjanthropus* may have looked. Below: the location in Africa where *Zinjanthropus* was found.

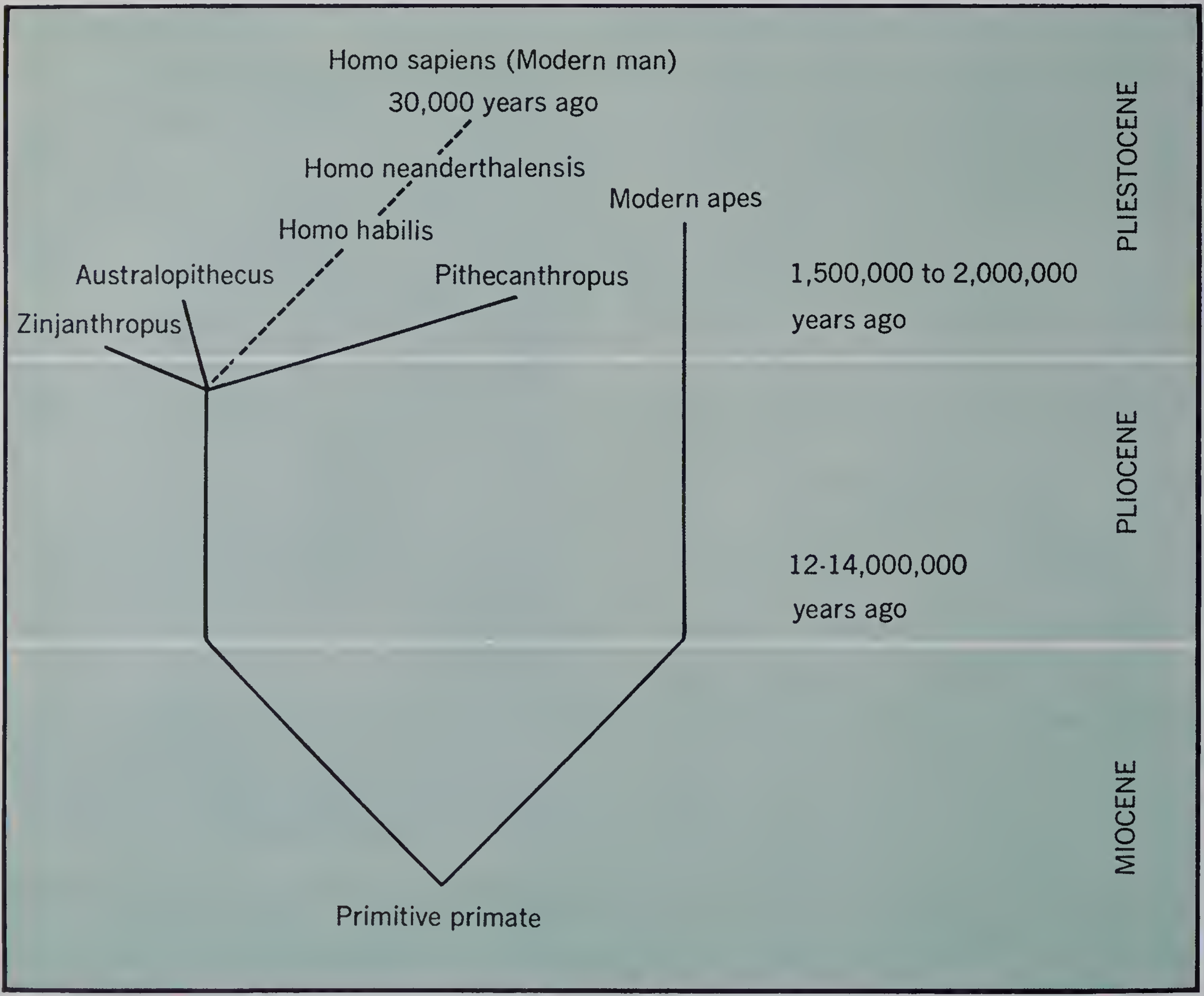


Neanderthal man lived in caves from which he journeyed on hunting expeditions in search of the hairy mammoth, saber-toothed tiger, and woolly rhinoceros. His brain was as large or larger than that of modern man. Neanderthal man used stone tools and weapons, made use of fire, buried his dead, and lived in a family group.

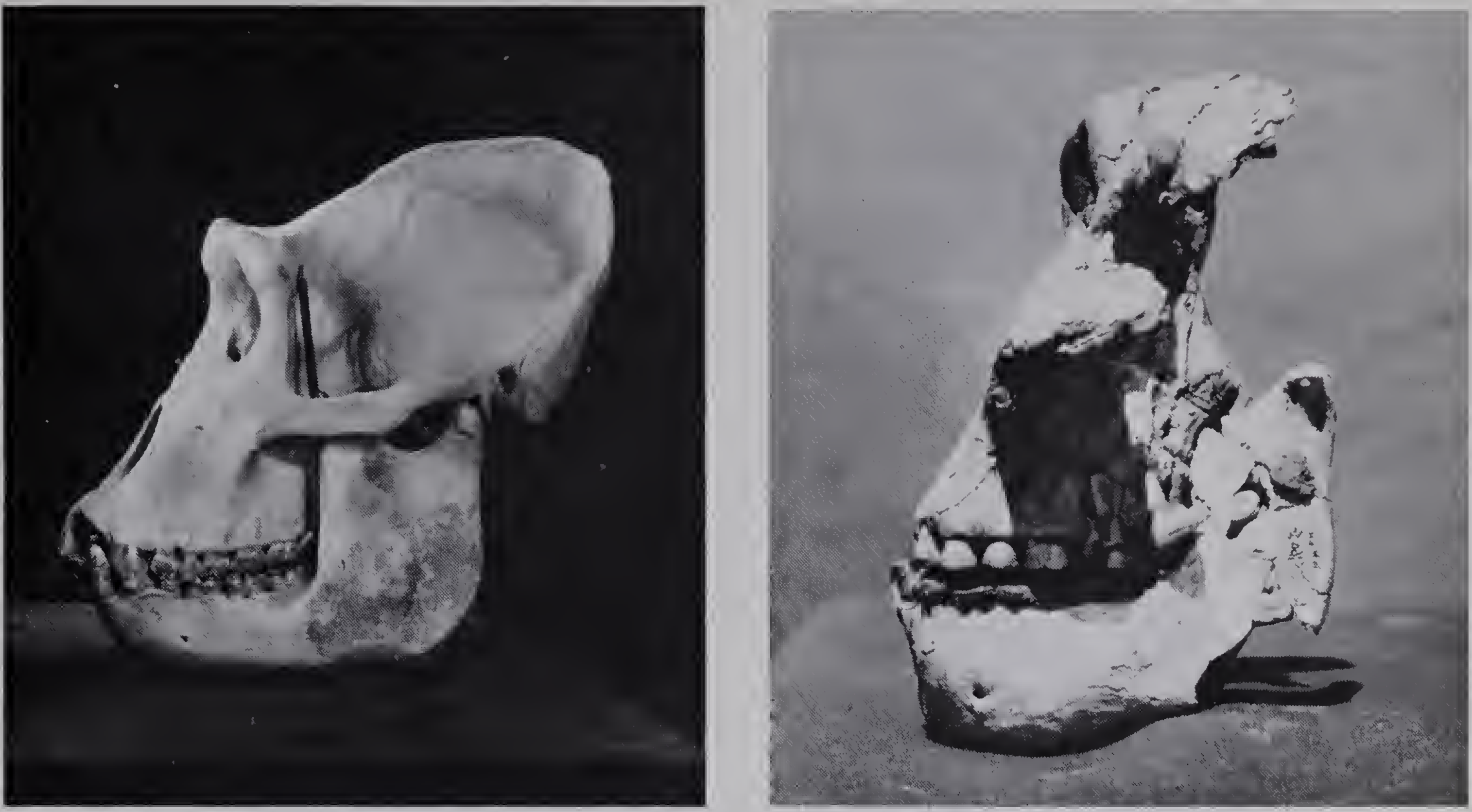
Cro-Magnon man. Anthropologists place ***Cro-Magnon man*** in the same species as modern man, ***Homo sapiens*** (*hoh*-moh *sayp*-ee-enz). He lived in Europe, especially in France and Spain, about 50,000 years ago. He had a high forehead and a well-developed chin, and lacked the heavy brow ridges of most of the more primitive men. Several caves along the southern coast of France have yielded Cro-Magnon weapons of stone and bone as well as skeletons. The walls of these caves bear beautiful drawings of animals of the region. These drawings have been valuable in dating the period. Anthropologists believe that Cro-Magnon man, living at the same time as Neanderthal man and being superior to him in intelligence, may have exterminated him. There is also evidence that Neanderthal man mixed with Cro-Magnon man and in time lost his identity.

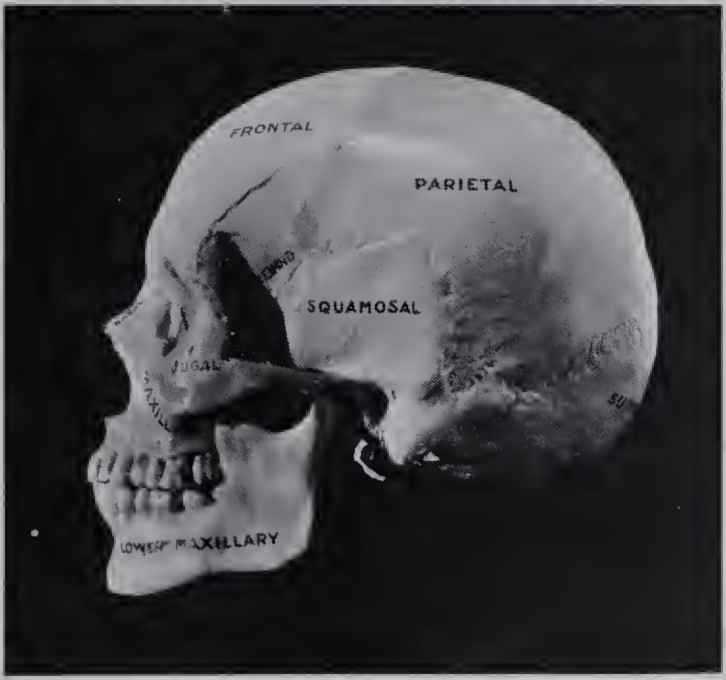
Modern man. All people living today belong to the species *Homo sapiens*. Anthropologists sometimes divide this single species into three or four racial groups, according to features that are common within each group. They recognize, however, that there is great variation within a racial group, and that all men are more alike than they are different.

The ***Mongoloid*** type is represented by people from most of Asia, the East Indies, and the Philippines. This type


Homo sapiens (Modern man)
30,000 years ago
Homo neanderthalensis
Modern apes
Homo habilis
Australopithecus
Pithecanthropus
Zinjanthropus
1,500,000 to 2,000,000
years ago
PLIESTOCENE
PLIOCENE
12-14,000,000
years ago
MIOCENE
Primitive primate

39-3 This chart represents Dr. Leakey's current theory of man's ancestry.





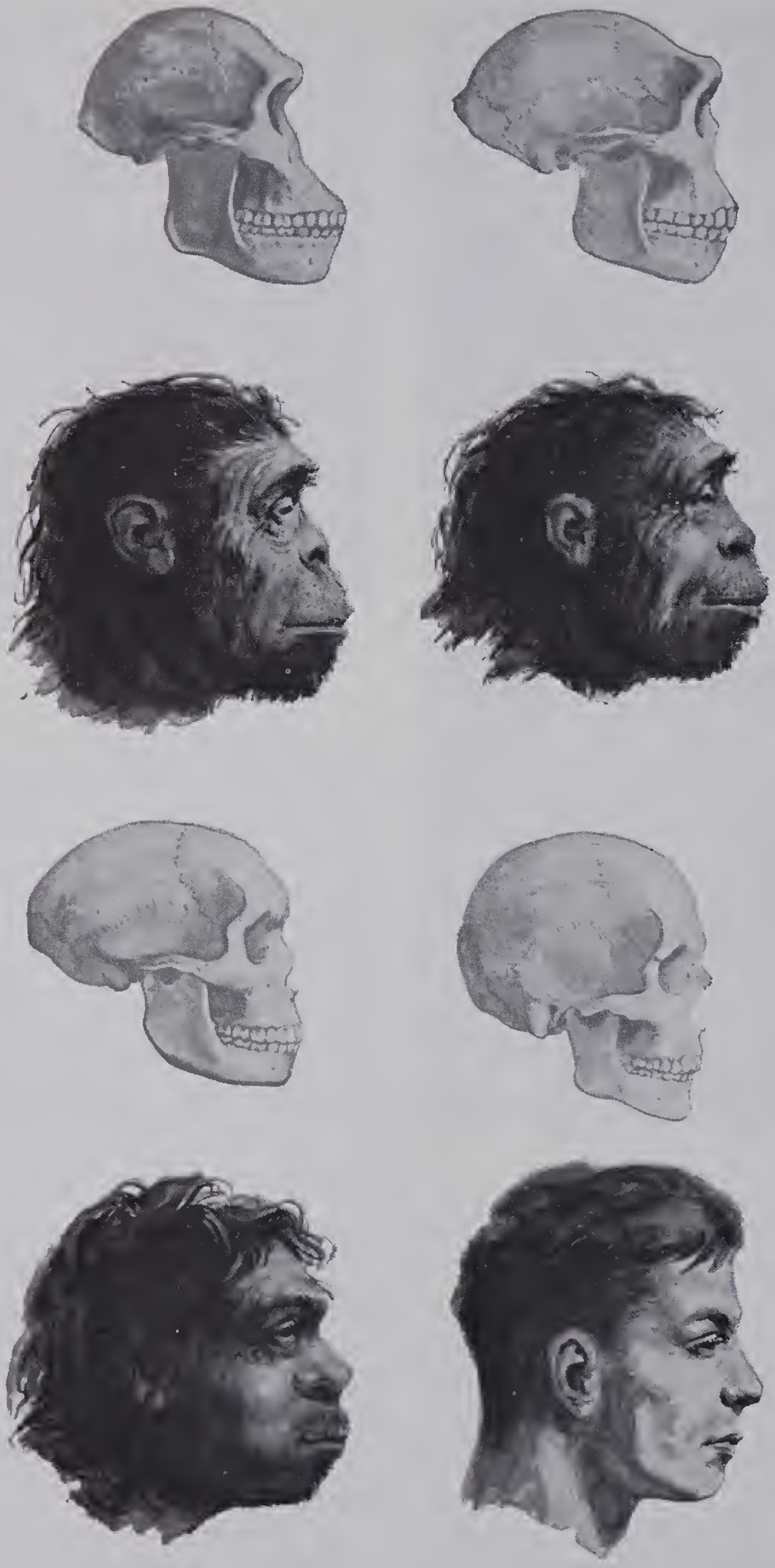
39-4 At the upper left is a gorilla skull and at the right is the skull of *Zinjanthropus*. Below them is the skull of modern man. How do these three differ? What does the structure of the teeth tell you about the possible method of defense of *Zinjanthropus* as compared to the gorilla? (© National Geographic Society, left; American Museum of Natural History, right and bottom)

is well represented in the Western Hemisphere by the Eskimos, and by the Indians of North America as well as Central and South America. Anthropologists believe that the Mongoloid people came to North America from Asia in very early migrations through Alaska.

Natives of North Africa, South Africa, East Africa, and the Congo pigmies comprise the ***Negroid*** type. Negroid stock is also found in New Guinea, the Philippines, and islands in the region of Australia.

People of the ***Caucasoid*** type are largely from Europe, Southwestern Asia, and North Africa. Caucasoid people vary greatly. They include the Teutonic types of Northern Europe and Iceland as well as the southern Europeans, Slavs, Hindus, Gypsies, Arabs, Jews, Egyptians, and Ethiopians.

A fourth type of modern man is represented by the ***Australoid*** type. These people do not fit any of the three major types. This small group includes the aborigines (original people) of Austral-



39-5 Various types of prehistoric man as compared to modern man. Top left: *Australopithecus;* top right: *Pithecanthropus;* bottom left: *Homo neanderthalensis;* bottom right: *Homo sapiens.*

ia and Ceylon. These primitive people still maintain a life typical of the early Stone Age. The sloping forehead and prominent brow ridge characteristic of the Australoids suggest a relationship to ancient man. However, the hand structure and body form are definitely like those of modern man. Anthropologists still have much to learn about these interesting people.

IN CONCLUSION

Intelligence combined with highly efficient hands and the ability to communicate separate man from the other mammals. It is believed by many anthropologists that, although man evolved along separate lines from the primates, the two forms may have had a common, generalized ancestor in the remote past.

An anthropologist is truly a detective. Although fossils are few and scattered, they provide valuable information regarding life in the past. By dating the fossils and comparing the structure of bones, the anthropologist is able to form hypotheses regarding primitive man, the food he ate, the tools he used, and the environment in which he lived. The comparison of manlike types does not mean, however, that one developed from another. There is no conclusive evidence to link the forms that have been found, dated, described, and compared. Modern man may have developed from forms that have not yet been located.

The next chapter will describe the structure of man as he exists today. It will be of vital concern because it is about you.

BIOLOGICALLY SPEAKING

anthropologist
Australoid
Australopithecus africanus
Caucasoid
Cro-Magnon man
half-life
Homo habilis
Homo sapiens
Mongoloid
Neanderthal man
Negroid
Pithecanthropus erectus
potassium-argon method
radiocarbon method
Zinjanthropus

QUESTIONS FOR REVIEW

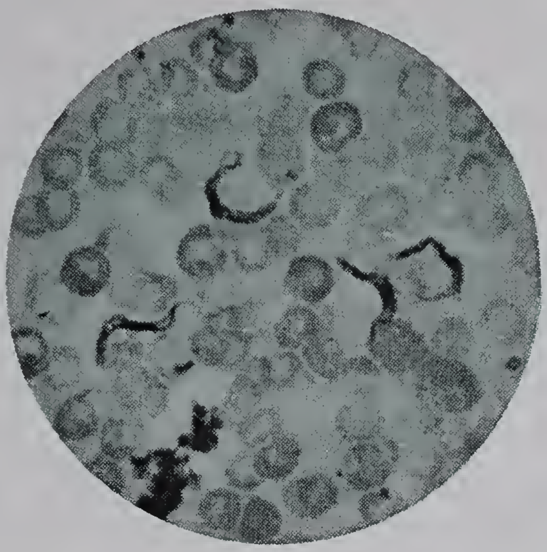
1. What characteristics separate man from other animals?
2. What did Charles Darwin believe about man's development, and what was the misunderstanding about his theory?
3. Why is the finding of an old skull important?
4. What can be learned from a study of the lower jaw and teeth?
5. How can we determine what type of environment occurred in a given area thousands of years ago?

6. How can we determine the diet of primitive man?
7. Describe two methods of dating fossils.
8. Describe *Australopithecus.*
9. Describe *Pithecanthropus erectus.*
10. Name the racial groups found in the world today, and give their place of origin.

APPLYING PRINCIPLES AND CONCEPTS

1. Do you think that tropical forests would provide good fossils? Explain your answer.
2. In what ways can the intelligence of primitive man be judged from fossil evidence?
3. Explain the theory that reduction of the canine teeth is related to tool making.
4. Compare the skull of modern man with those of Java, Neanderthal, and Cro-Magnon men.
5. Did Cro-Magnon man have any methods of communication? Explain.
6. How could agriculture have developed from a settled life?

CHAPTER 40



THE BODY FRAMEWORK

Tissues of the human body. No topic is more important to you than your own body. Like any other organism the human body is made up of cells and their products. All the cells of the body can be placed into four groups: 1. connective tissue, 2. muscle tissue, 3. nerve tissue, and 4. epithelial tissue (see table on page 553). You will study muscle tissue in this chapter and nerve tissue in a later chapter.

Connective tissue lies between groups of nerve and muscle cells. It fills up spaces in the body that are not occupied by specialized cells, and it forms protective layers (Fig. 40–1). Connective tissue also binds together many softer tissues and gives them strength and firmness. Fibrous tissues in the walls of organs, the tendons of muscles and ligaments binding bones, as well as the bones themselves are all types of connective tissue. Blood and lymph are also connective tissue.

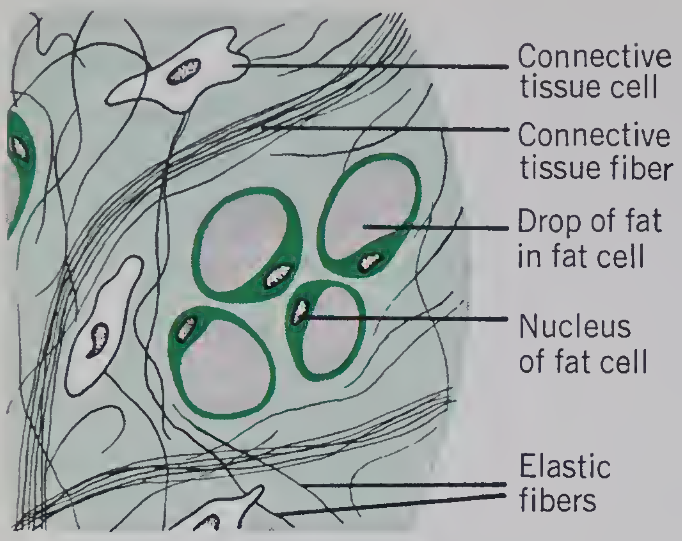
Epithelial (ep-i-*thee*-lee-al) ***tissue*** is the type that covers the body surfaces, both inside and outside. For example, certain flat epithelial cells cover the blood vessels and heart. Another type of epithelium lines the stomach. Some cells of this lining are modified to secrete mucus and other stomach secretions. Still another epithelial tissue forms the skin, and another the ciliated lining of the trachea.

Tissues are organized into organs and systems. Familiar examples of organs in the human body include the arms, legs, ears, eyes, heart, liver, and lungs. Each of these organs is specialized to perform a definite function or a group of related functions involving several different tissues. The arms, for example, are composed of epithelial tissue, bone, blood, lymph, cartilage, muscle, and nerve tissues. All of these function together to perform such acts as grasping, writing, and sewing.

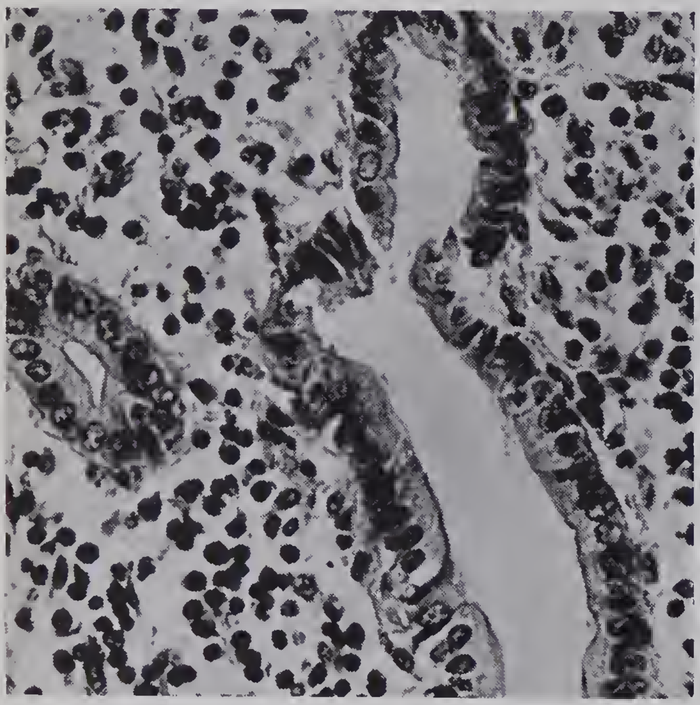
Organs are grouped together into ten systems, as follows:

1. Skeletal (bones and cartilage)
2. Muscular (muscles)
3. Digestive (teeth, mouth, esophagus, stomach, intestines, liver, pancreas)
4. Respiratory (lungs, trachea, nose, pharynx)
5. Circulatory (heart, arteries, veins, capillaries)
6. Endocrine (ductless glands)
7. Excretory (kidneys and bladder)
8. Integumentary (skin and hair)
9. Nervous (brain, spinal cord, nerves, eyes, ears)
10. Reproductive (testes, ovaries, uterus, oviducts)

The body regions in man. The general form of the human body is similar to that of the other vertebrate animals. It includes the limbs (in the form of arms and legs), the head, neck, and trunk.



40-1 When viewed under the microscope, connective tissue appears like this.



40-2 This photomicrograph shows simple columnar epithelial cells in the lining of the small Intestine. (Walter Dawn)

The head includes the ***cranial cavity,*** which is formed by the bones of the skull and safely encloses the brain. The head also contains the sense organs, which are located close to the brain, to which they transmit impulses.

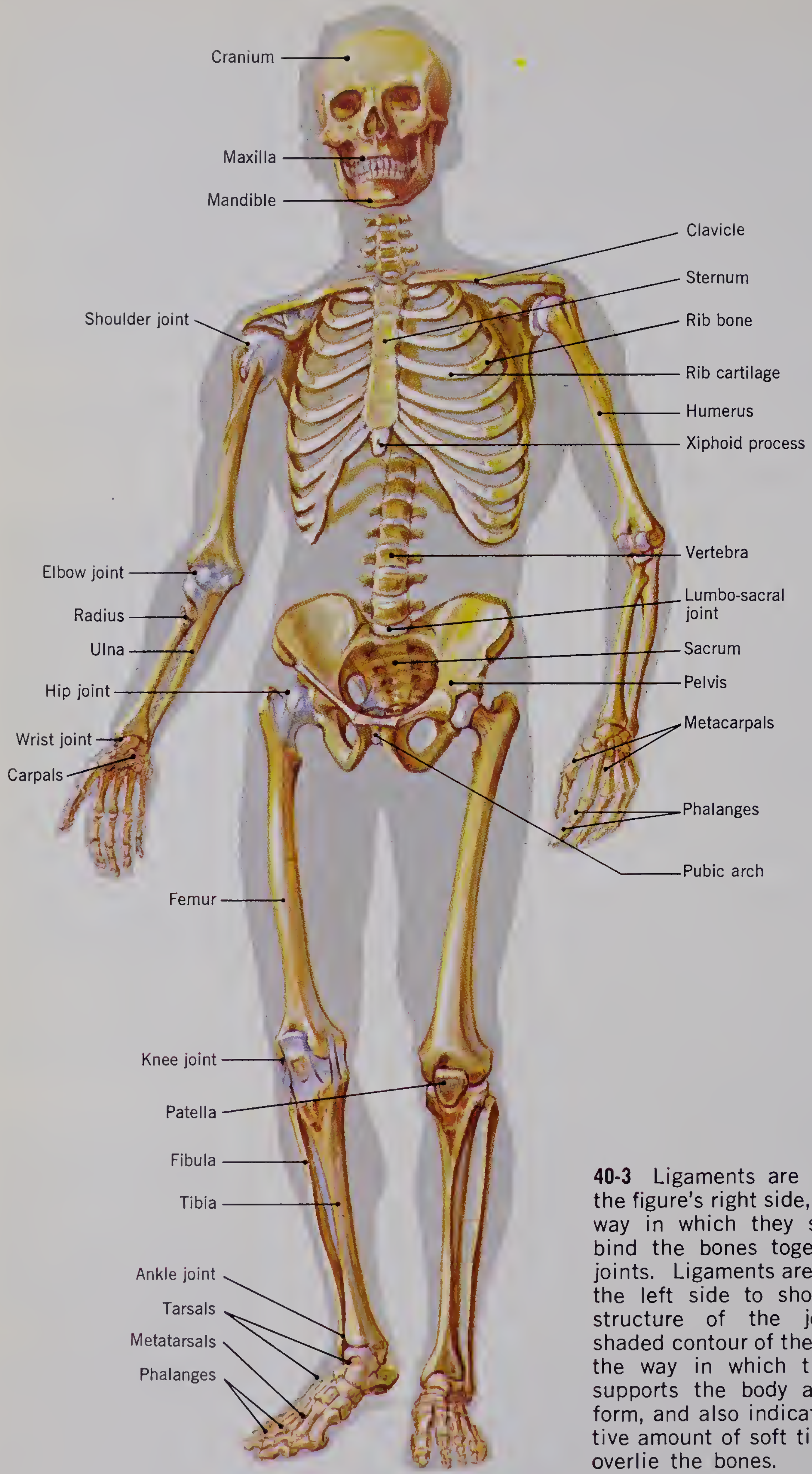
The ***thoracic cavity*** is formed by the ribs, breastbone, and spine. It encloses the lungs, the trachea, the heart, and the esophagus. A dome-shaped partition, the ***diaphragm,*** separates the thoracic cavity from the ***abdominal cavity,*** which is included in the lower part of the trunk. Inside the abdominal cavity are the stomach, liver, pancreas, intestines, spleen, kidneys, and in the female, the ovaries. While the abdominal organs lack the bony protection of the cranial and thoracic cavities, they are protected by the vertebral column along the back and by layers of skin and muscle on the front.

The body framework. In building a model airplane the framework of the body is usually built first. Then comes the covering and painting, and finally the motor, wheels, and accessories. The strength of the entire structure depends on the framework to which all the other parts are fastened. Man and the other vertebrates, like the model airplane, have a very efficient system of support in the form of an internal skeleton, or ***endoskeleton.*** You will recall that the arthropods have an exoskeleton. Man's bony framework gives him the greatest support with the least amount of weight. It also permits more efficient movement than any other type of framework. The animal with an internal skeleton is, however, at one great disadvantage. It does not have much of the protection against injury from the outside that is given by an external skeleton. Many soft parts of the body are exposed. Consequently, the organism must rely on its nervous system and sense organs to make up for the protection the skeleton does not provide.

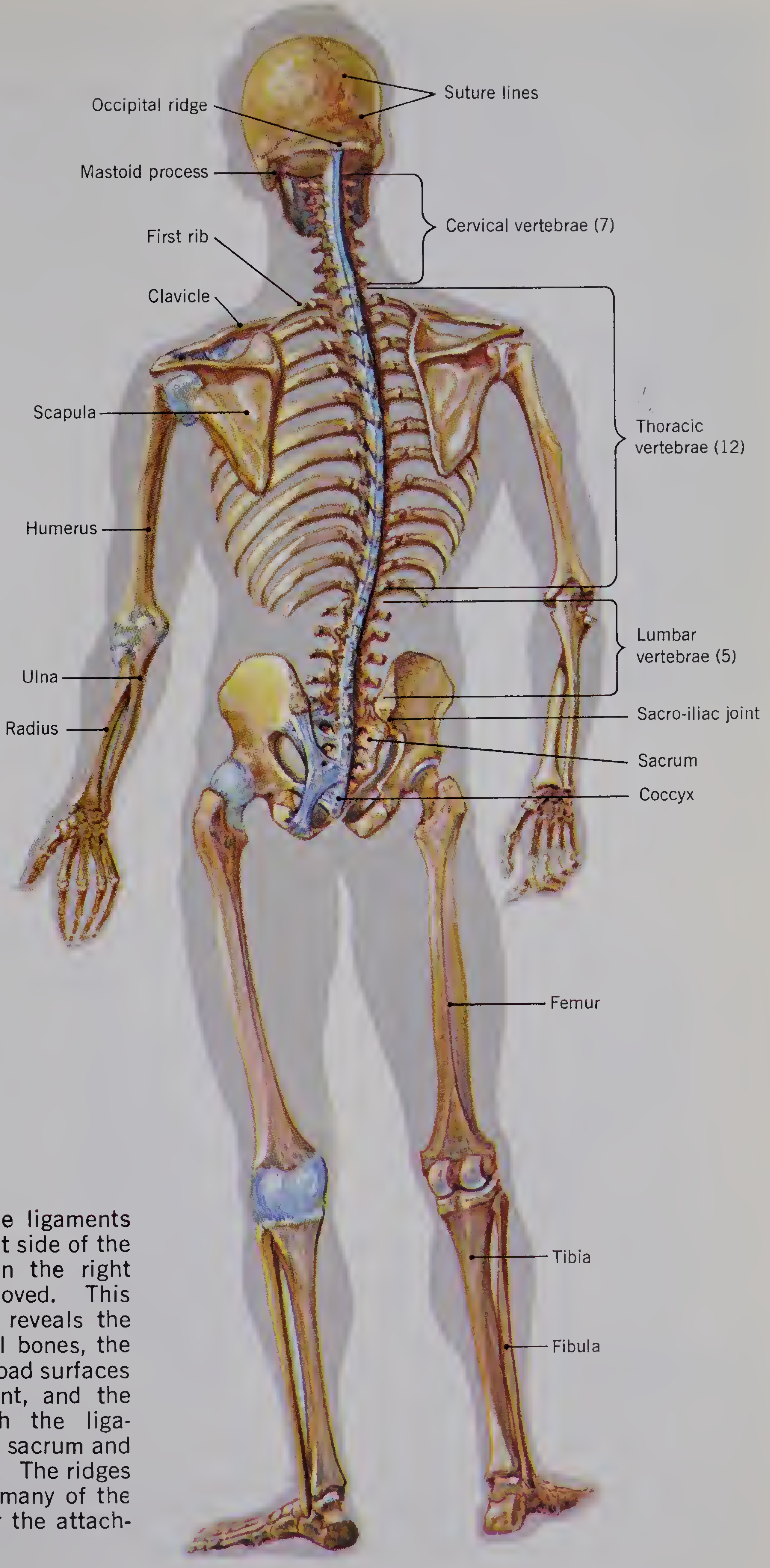
The functions of the skeleton. The functions of the bones of the body are classified as follows: 1. support and form for the body; 2. place for the attachment of muscles; and 3. protection for delicate organs. Many of the 206 bones composing the human skeleton have more than one function. For example,

TISSUES IN THE HUMAN BODY

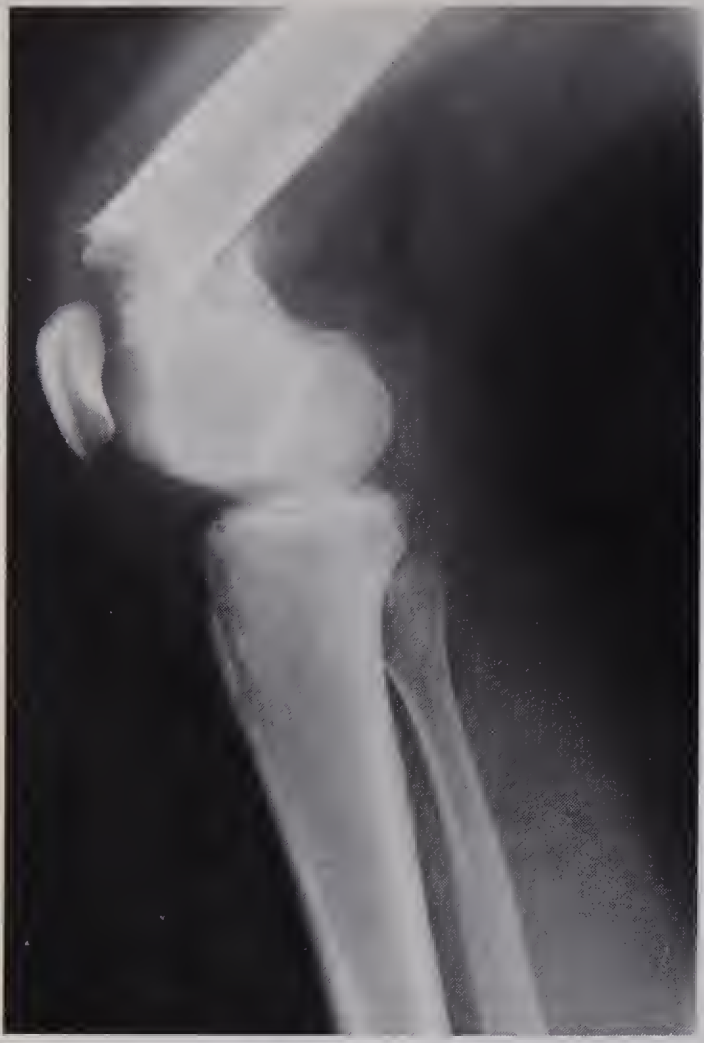
Tissue	*Occurrence*	*Function*
I. CONNECTIVE TISSUE		
A. Bone	Skeleton	Composes framework and allows for movement
B. Cartilage	Outer ears, ends of long bones, larynx, tip of nose, between vertebrae, juncture of ribs and breastbone, trachea	Acts as cushion, lends rigididy to structures that lack bones, provides slippery surface to some joints
C. Dense fibrous connective tissue		
1. Regularly arranged	Tendons, ligaments	Joins muscles to bones or bone to bone to aid in movement
2. Irregularly arranged	Membrane around bone (periosteum), one of the membranes around spinal cord and brain (dura mater), inner layer of skin	Provides protection and carries blood supply
D. Loose fibrous connective tissue		
1. Fibroelastic (elastic — strong, closely woven)	Capsules of organs	Holds organ together
2. Fibroareolar (areolar — loosely woven)	Facial area beneath skin	Acts as filler tissue
3. Reticular	Surrounding individual cells and muscle fibers	Acts as filler tissue
4. Adipose	Around organs, beneath skin	Cushions and insulates, stores fat
E. Liquid tissue		
1. Blood	In heart and vessels (arteries and veins)	Has essential part in: respiration, nutrition, excretion, regulation of body temperature, protection from disease
2. Lymph	Fluid in tissue spaces between cells, cerebrospinal fluid	Bathes the cells, has part in nutrition and protection from disease
II. MUSCLE TISSUE		
A. Smooth	In internal organs	Produces either voluntary or involuntary movement
B. Skeletal	Attached to bones, tendons, and other muscles	
C. Cardiac	In heart	
III. NERVE TISSUE	Brain, spinal cord, nerves	Carries impulses that cause muscles to contract, carries messages to brain to inform individual about the environment
IV. EPITHELIAL TISSUE	1. Covering surface of body (skin), lining nose, throat, and windpipe, lining all of digestive tract 2. Many glands	Provides protection, produces secretions


Cranium
Maxilla
Mandible
Clavicle
Sternum
Shoulder joint
Rib bone
Rib cartilage
Humerus
Xiphoid process
Vertebra
Elbow joint
Lumbo-sacral joint
Radius
Ulna
Sacrum
Hip joint
Pelvis
Metacarpals
Wrist joint
Carpals
Phalanges
Pubic arch
Femur
Knee joint
Patella
Fibula
Tibia
Ankle joint
Tarsals
Metatarsals
Phalanges

40-3 Ligaments are in place on the figure's right side, showing the way in which they support and bind the bones together at the joints. Ligaments are removed on the left side to show the bony structure of the joints. The shaded contour of the body shows the way in which the skeleton supports the body and gives it form, and also indicates the relative amount of soft tissues which overlie the bones.


Suture lines
Occipital ridge
Mastoid process
Cervical vertebrae (7)
First rib
Clavicle
Scapula
Thoracic vertebrae (12)
Humerus
Lumbar vertebrae (5)
Ulna
Sacro-iliac joint
Radius
Sacrum
Coccyx
Femur
Tibia
Fibula

40-4 In this view, the ligaments are in place on the left side of the figure while those on the right side have been removed. This view of the skeleton reveals the sutures of the cranial bones, the scapulae with their broad surfaces for muscle attachment, and the sacro-iliac joint with the ligaments which bind the sacrum and pelvic bones together. The ridges which are visible on many of the bone surfaces are for the attachment of muscles.



40-5 This is an X-ray photograph of a complete fracture and separation of the lower end of the thighbone (femur) just above the knee joint. (Indiana University Medical Center)

the vertebral column, the shoulder girdle, the hip girdle, the bones of the legs, and those of the arms both support the body and give it definite form. Some of these bones also have muscles attached to them, permitting the many types of movement (Figs. 40–3 and 40–4, pages 554 and 555). Certain delicate organs lie under special protective bones. Examples are the brain, which is encased by the cranial bones; the heart, which lies under the sternum; and the lungs, which are protected by the ribs.

The development of bone tissue. We use the expression "dry as a bone," and assume that living bone is like a dried-out bone. Actually, living bone is far from dry. It is moist and active and requires nourishment as does any living organ. True, part of what we call bone is nonliving, for bone tissue is a peculiar combination of living cells and their products and mineral deposits.

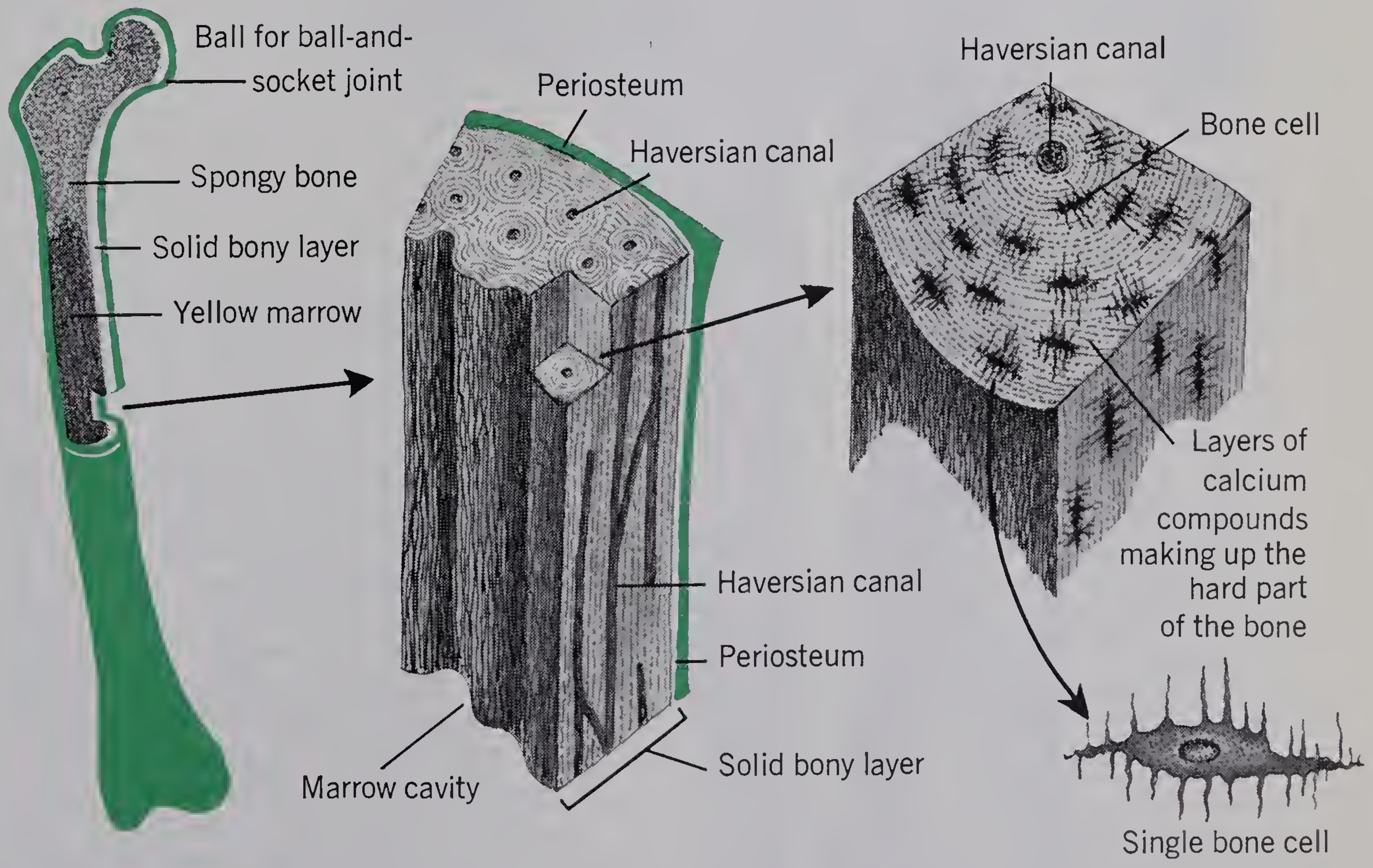
Among some of the lower vertebrates the skeleton is composed entirely of cartilage, which lasts throughout their lives and results in a tough, flexible skeleton. In the early stages of the development of the human embryo, the skeleton is also composed almost entirely of cartilage, with a few membranes taking the place of bone in some regions. After about the second month of development, however, certain of the cartilage cells disappear and are replaced by bone cells. These cells deposit minerals in the form of calcium phosphate and calcium carbonate in the spaces between them. This process is called ***ossification*** (ahs-i-fi-*kay*-shun) and occurs throughout childhood. Even in the adult, however, some cartilage is not replaced by bone. Such permanent cartilage is found in the end of the nose, the external ear, and the walls of the voice box and trachea.

Since ossification involves the deposit of calcium compounds between the bone cells, it results in an increase in the strength of the bone. Naturally, this deposition cannot occur unless the proper minerals are present. Calcium compounds enter the body with food and are carried to the bone tissues by the blood. The diet, especially in childhood, is therefore an important factor in governing mineral deposition in bone. Milk, the natural food of all young mammals, is the ideal source of calcium compounds. Developing bone tissue must assimilate the minerals after they have been supplied by a proper diet. Certain vitamins, especially vitamin D, are necessary for the normal growth of bone. We shall study these in Chapter 41 under vitamins.

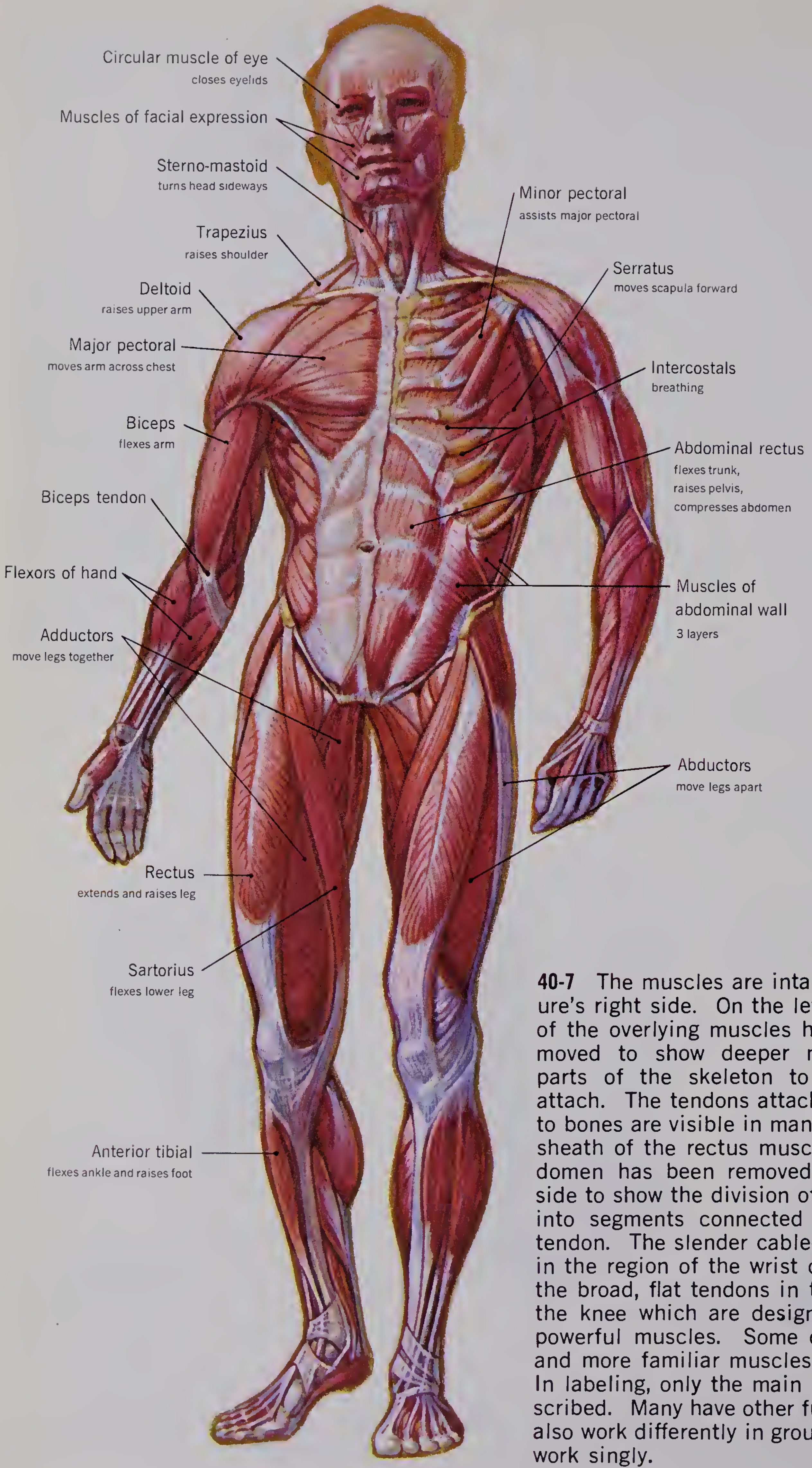
Bones grow along lines of stress. This means that they become heaviest and strongest where the strain is greatest. This fact is important in dealing with bone fractures. If a broken bone is protected by a cast and is unused during the period of repair, the fact that it is under no stress delays healing. For example, if a leg bone is broken the patient is provided with a walking cast, which puts a broken bone under limited stress during the healing period and speeds up the repair process. If, on the other hand, a limb is paralyzed or made useless, the minerals are reabsorbed by the blood and deposited elsewhere.

The structure of a bone. If a long bone, such as a bone from the leg or thigh is cut lengthwise, several distinct regions can be seen (Fig. 40–6). The outer covering is a tough membrane called the ***periosteum.*** This membrane aids in nourishing the bone (because of its rich blood supply) and in repairing injuries; it also provides a surface to which muscles are attached. Beneath the periosteum is a ***bony layer*** containing the deposits of mineral matter. This layer varies in hardness from an extremely hard material in the middle region to a porous and spongy material at the ends. The bony layer is penetrated by numerous channels, the ***Haversian canals,*** which form a network extending throughout the region. These canals carry nourishment to the living cells of the bony layer, by means of blood vessels that connect with those of the outer membrane.

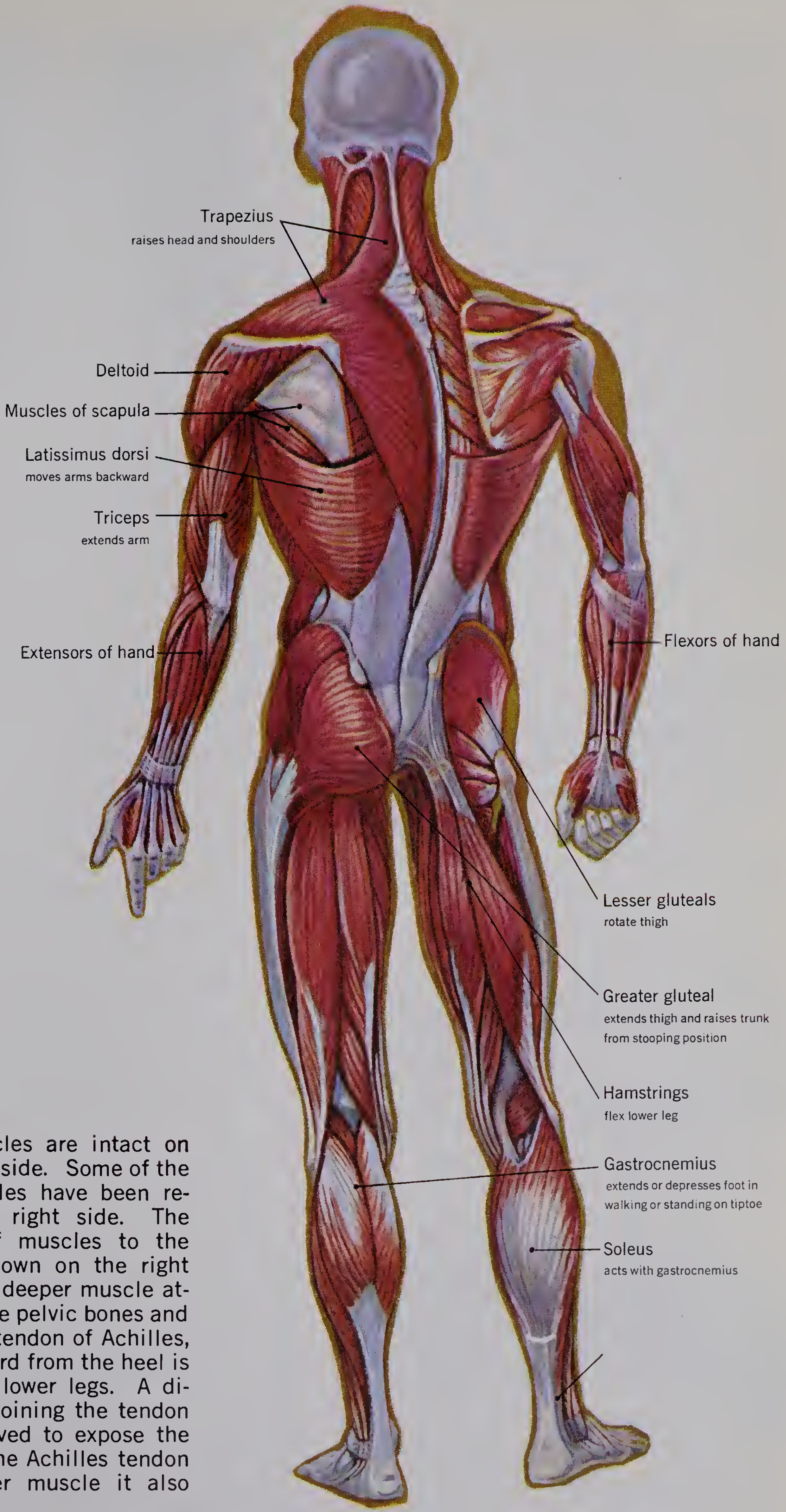
Many bones have hollow interiors and contain a soft tissue called marrow. The marrow is richly supplied with nerves and blood vessels. There are two distinct types of marrow. The ***red***


Ball for ball-and-socket joint
Spongy bone
Solid bony layer
Yellow marrow
Periosteum
Haversian canal
Haversian canal
Periosteum
Solid bony layer
Marrow cavity
Haversian canal
Bone cell
Layers of calcium compounds making up the hard part of the bone
Single bone cell

40-6 A cutaway view of the human femur appears to the left. The center drawing shows an enlarged section of that bone. On the right we see the Haversian canal system as well as an enlarged view of a single bone cell.


Circular muscle of eye
closes eyelids
Muscles of facial expression
Sterno-mastoid
turns head sideways
Trapezius
raises shoulder
Deltoid
raises upper arm
Major pectoral
moves arm across chest
Biceps
flexes arm
Biceps tendon
Flexors of hand
Adductors
move legs together
Rectus
extends and raises leg
Sartorius
flexes lower leg
Anterior tibial
flexes ankle and raises foot
Minor pectoral
assists major pectoral
Serratus
moves scapula forward
Intercostals
breathing
Abdominal rectus
flexes trunk,
raises pelvis,
compresses abdomen
Muscles of
abdominal wall
3 layers
Abductors
move legs apart

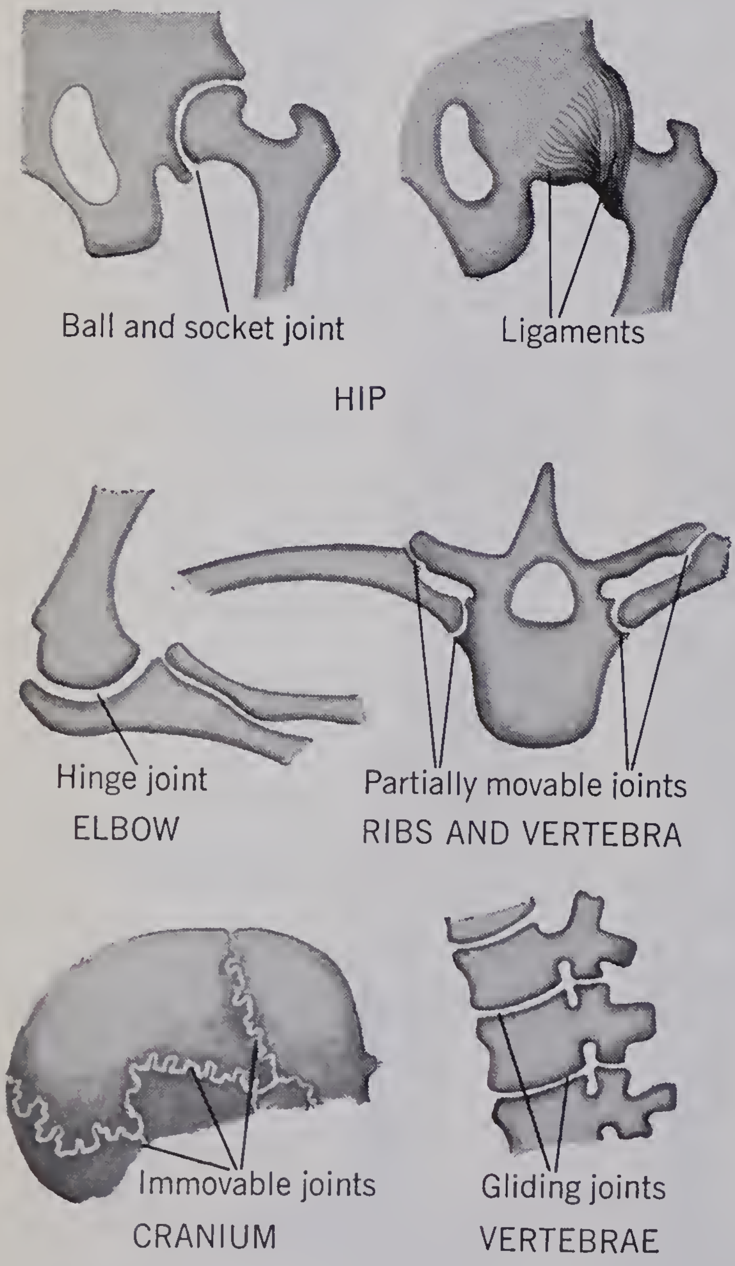
40-7 The muscles are intact on the figure's right side. On the left side, some of the overlying muscles have been removed to show deeper muscles and parts of the skeleton to which they attach. The tendons attaching muscles to bones are visible in many areas. The sheath of the rectus muscle of the abdomen has been removed on the left side to show the division of this muscle into segments connected by areas of tendon. The slender cable-like tendons in the region of the wrist contrast with the broad, flat tendons in the region of the knee which are designed for more powerful muscles. Some of the larger and more familiar muscles are labeled. In labeling, only the main action is described. Many have other functions and also work differently in groups than they work singly.


Trapezius
raises head and shoulders
Deltoid
Muscles of scapula
Latissimus dorsi
moves arms backward
Triceps
extends arm
Extensors of hand
Flexors of hand
Lesser gluteals
rotate thigh
Greater gluteal
extends thigh and raises trunk from stooping position
Hamstrings
flex lower leg
Gastrocnemius
extends or depresses foot in walking or standing on tiptoe
Soleus
acts with gastrocnemius

40-8 The muscles are intact on the figure's left side. Some of the overlying muscles have been removed on the right side. The attachments of muscles to the scapula are shown on the right side as are the deeper muscle attachments to the pelvic bones and hip joint. The tendon of Achilles, extending upward from the heel is shown in both lower legs. A divided muscle, joining the tendon has been removed to expose the full length of the Achilles tendon and the deeper muscle it also joins.

marrow is found in flat bones such as the ribs and sternum, as well as in the ends of long bones and vertebrae. It is active in forming the red corpuscles and most of the white corpuscles. The *yellow marrow* fills the central cavity of long bones and extends into the Haversian canals of the bony layer. It is normally inactive and primarily composed of fat cells, but may produce corpuscles in time of great blood loss and in certain blood diseases.

The smaller bones are solid rather than hollow and vary considerably in the amount of spongy bone tissue present. Although they are solid, they are completely penetrated with blood vessels.

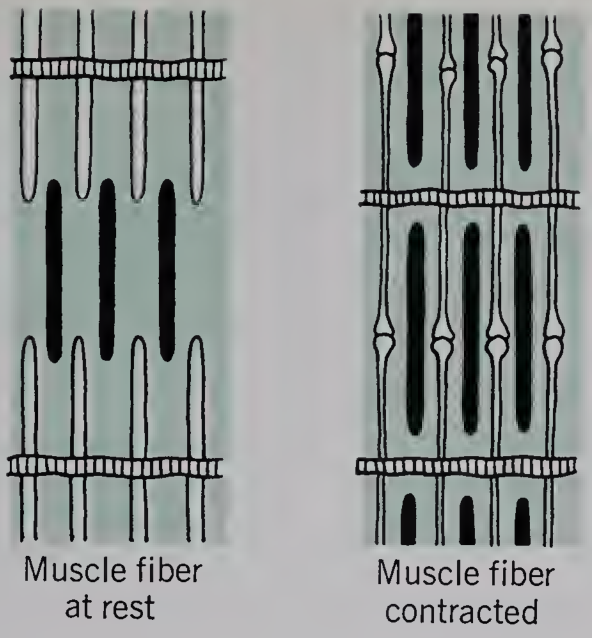


40-9 The five types of joints.

The joints of the body. The point at which two separate bones meet is called a ***joint.*** The various bones of the human body are connected by several different kinds of joints (Fig. 40–9). The elbow is an example of a *hinge joint.* Such a joint moves as a hinge in one plane only, but may give great power because there is little danger of twisting. When the biceps muscle of the upper arm contracts, the lower arm is pulled upward only. The knee is another example of a hinge joint. The hip and shoulder joints are examples of *ball-and-socket* joints. Here the bone of the upper arm ends in a ball which fits into a socket of the shoulder girdle. Such a joint has the advantage of movement in any direction within the limits imposed by the muscles. The hip joint is similar to that of the shoulder, with a ball on the end of the *femur,* or thighbone, fitting into a socket of the hipbone, the *pelvis.* Ball-and-socket and hinge joints are held in place by tough strands of connective tissue called ***ligaments.*** Ligaments may be stretched with exercise, thus loosening joints and permitting freer movement.

The ribs are attached to the *vertebrae* by joints that are only *partially movable.* Long strands of cartilage attach the ribs to the breastbone in front to allow for chest expansion during breathing. The junction between the spine and pelvis, the sacroiliac joint, is a well-known example of partial movability. It is frequently injured in sudden falls. Some joints, such as those in adult skull bones, are *immovable.* Other joints include the *angular joints* of the wrists and ankles, the *gliding joints* of the vertebrae, and the *pivot joint* of the head on the spine.

The inner surfaces of the joints are covered with layers of permanent carti-



40-10 This diagram illustrates the current theory of muscle contraction. It is believed that the tiny myofibrils slide together in the manner shown, resulting in a shortening of the muscle.

lage. A secretion called ***synovial*** (se-*noh*-vee-al) ***fluid*** serves to lubricate the joints. In some joints, such as the knee or shoulder, a sac called the ***bursa*** serves as a cushion between the bones.

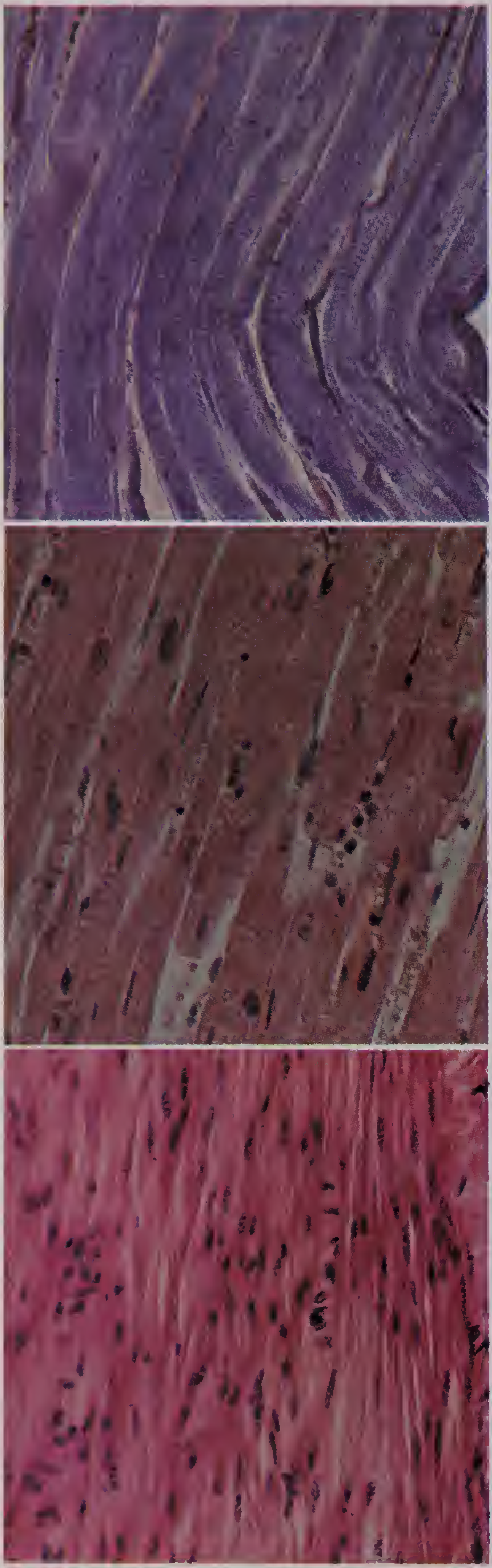
How muscles produce movement. Bones, even in a living body, have no power to move by themselves. Muscle cells, however, are specialists in motion because of their ability to contract. Grouped in bundles, these cells accomplish such mechanical activities as walking, grasping, breathing, heartbeat, and movement of the digestive organs. There are about 400 different muscles in the human body, making up about one half of the body weight (Figs. 40–7 and 40–8, pages 558 and 559).

Muscle tissues of man and other higher animals are composed of bundles of long slender cells often called muscle *fibers.* Each of these consists of numerous fine threads called *myofibrils,* which lie parallel and run lengthwise in the fiber. The myofibrils in turn are bundles of two distinct kinds of still smaller protein filaments — thick and thin. These are arranged in the myofibril in a definite pattern (Fig. 40–10).

When muscle cells, or fibers, are supplied with energy from ATP and activated by a nerve impulse, they contract. The actual mechanism by which muscle cells contract is not known, but a widely accepted current theory states that the thick and the thin protein filaments slide past each other, in a manner that would shorten the myofibrils.

Each nerve cell that carries impulses to a muscle branches to supply a small number of muscle fibers. The nerve cell and the individual fibers it stimulates comprise what is called a *motor unit.* Each fiber, when stimulated to contract, will do so to its fullest. The factor that determines whether a movement will be a very delicate, precise one or a very forceful one is therefore the number of motor units that are called into action. Muscle fibers may also be stimulated to contract by heat, light, chemicals, pressure, and electricity.

Types of muscle cells. The three types of vertebrate muscle cells are shown in Fig. 40–11. ***Smooth muscle*** forms the walls of many internal organs. Each cell in smooth muscle is an elongated spindle containing one nucleus usually situated near the center of the cell. The stomach and intestinal walls contain layers of smooth muscle cells which contract in waves to churn food or pass it along through the digestive tract. Artery walls also contain layers of smooth muscle. Impulses from the nervous system cause the artery walls to constrict and raise the blood pressure during danger or emotional upset. All action of smooth muscle is controlled by parts of the nervous system over which we have no conscious control, so that smooth muscle is a type of *involuntary* muscle.



The ***skeletal muscles*** may be controlled at will and are therefore *voluntary* muscles. Each fiber is a long cylinder with tapering ends and contains many nuclei situated near the periphery of the cell throughout its length. Skeletal muscle fibers do not run the entire length of most muscles but are bound together in small bundles by connective tissue sheaths. These small bundles are then held together by a heavier sheath which encloses the entire muscle. This structure gives most voluntary muscles a spindle shape.

Some skeletal muscles attach directly to bones, some attach to other muscles, and some attach to bones by inelastic ***tendons*** extending from the tapered end. These tendons are dense bands of fibrous connective tissue. Since muscles are organs of movement, they must attach at two points. The ***origin*** is stationary while the ***insertion*** is the attachment of the muscle on the movable part. Be sure to note the origin and the insertion of the *biceps* in Fig. 40–12.

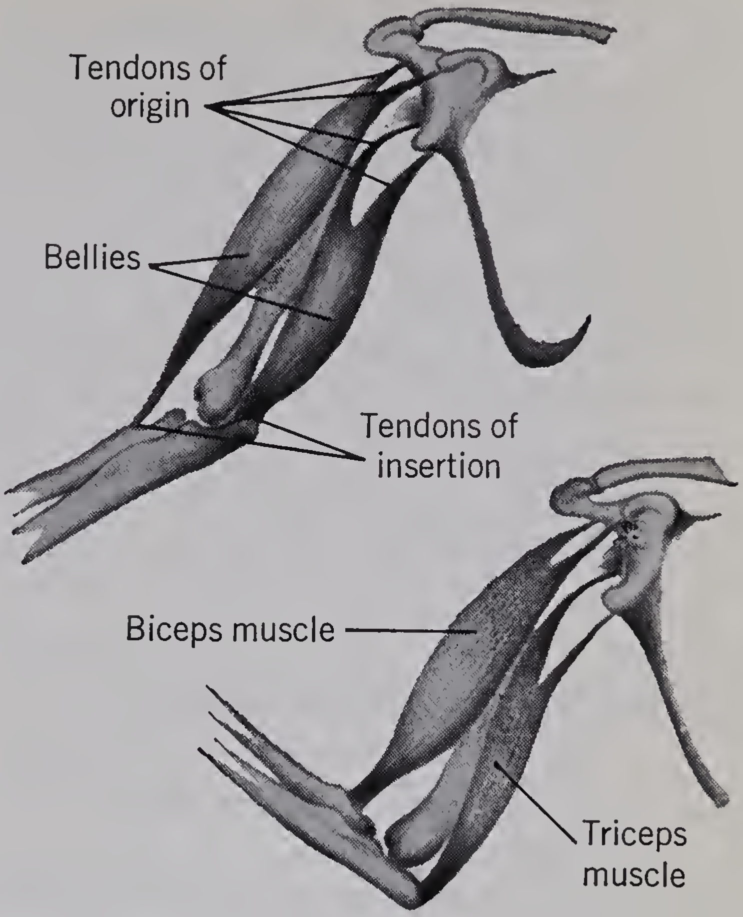
The skeletal muscles that move joints of the trunk and limbs are always arranged in pairs. Muscles that bend joints are called ***flexors,*** while those that straighten them are called ***extensors.*** For instance, when you bend your elbow joint, the tendon of the contracted biceps muscle raises the radius bone of the forearm. The other end of this muscle is securely anchored at the shoulder. During this contraction you can feel the biceps muscle swell on the front side of your upper arm. The extensor muscle involved in this movement is

40-11 Top: photomicrograph of stained skeletal muscle; middle: cardiac muscle; bottom: smooth muscle. (Walter Dawn) called the *triceps.* It is on the back side of the upper arm. When you lower the arm, the triceps contracts and the biceps relaxes. If you straighten your arm completely, you can feel this muscle contract.

Even when a joint is not being moved, flexor and extensor muscles oppose each other in a state of slight contraction called ***tone.*** Increased use of muscles results in enlargement and increased tone. When totally unused, muscles become weak and flabby, decrease in size, and lose tone.

Cardiac muscle, the involuntary muscle found in the heart, is made up of the third kind of contractile cell in the body. Structurally cardiac muscle resembles skeletal muscle except that the fibers branch and join others to form an interlacing meshwork. Thus, when cardiac muscle fibers contract, the cavities of the heart are squeezed and blood is forced out through the vessels.

The action of heart muscle is unlike that of any other muscle. It has an automatic beat which is conducted from cell to cell throughout the muscle. The beat originates in a small mass of tissue in the wall of the right atrium of the heart, called the ***sinoatrial node.*** From this point the beat is carried through the muscle of the upper chambers to another node, the ***atrioventricular node,*** where it is relayed through the muscles of the lower chambers. Conduction of the beat through the cells of heart muscles results in the characteristic rhythmic wave of contraction.



40-12 In the upper drawing the arm is straightened by the contraction of the triceps muscle, while the biceps is relaxed. In the lower drawing the biceps contracts to flex the arm while the triceps relaxes.

IN CONCLUSION

The human body is organized into tissues, organs, and systems. The body framework consists of an internal skeleton composed of bones that give the body form, act as levers for muscles, and protect the more delicate organs.

Muscles produce movement. Those that are attached to bones by means of tendons are skeletal muscles. Smooth muscles form layers in the walls of such internal organs as the stomach, intestines, and the arteries. Their control is involuntary.

Our attention will next be focused on the nature of foods and nutrition in a living organism. If we know what foods are and what they do, we can then study the digestive system with better understanding.

BIOLOGICALLY SPEAKING

abdominal cavity
atrioventricular node
bony layer
bursa
cardiac muscle
connective tissue
cranial cavity
diaphragm
endoskeleton
epithelial tissue
extensor
flexor
Haversian canal
insertion
joint
ligament
origin
ossification
periosteum
red marrow
sinoatrial node
skeletal muscle
smooth muscle
synovial fluid
tendon
thoracic cavity
tone
yellow marrow

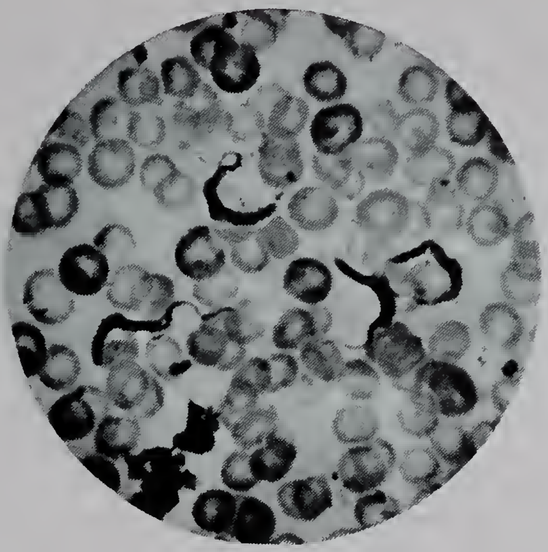
QUESTIONS FOR REVIEW

1. How do the tissues, organs, and systems of the human body illustrate division of labor?
2. What are the three body cavities? By what structures are they enclosed? Name some of the organs found in each.
3. What are the principal functions of bones? Give an example of a bone serving each purpose.
4. What are some important functions of the Haversian canals?
5. Describe some of the tissues surrounding a joint.
6. Describe four kinds of joints found in the body.
7. How do we classify muscle cells as to appearance, control, and location?
8. Why are muscles often found in opposing pairs in the body?
9. Describe the contraction of a striated muscle.

APPLYING PRINCIPLES AND CONCEPTS

1. Explain why an organism with an internal skeleton must have a highly developed nervous system.
2. Proper diet alone does not insure good teeth and healthy bones. What other factors are involved?
3. How does a walking cast speed up the repair of a bone fracture?
4. Why can the heart of some lower animals be removed and kept beating in a nutrient solution?

CHAPTER 41



NUTRITION

What is food? Some time after you eat a sandwich and drink a glass of milk, these substances are still in your tissues. But in what form — as bread, beef, milk, and butter? No. These foods have been changed to glucose, amino acids, and fatty acids. How did this happen? As the foods passed through the alimentary canal, a 30-foot tube, several enzymes broke them down chemically in a series of changes that make up the process of digestion. Your digestive system is like an assembly line in reverse. It starts with the many complex foods you eat and simplifies them to a few nutrients. Food is any substance which, when absorbed into the body tissues, yields materials for the production of energy, the growth and repair of tissue, and the regulation of life processes, without harming the organism. This is another way of saying that you eat to be active and to grow and to maintain your body. Six classes of substances meet the requirements of this definition: 1. water; 2. minerals; 3. carbohydrates, 4. fats; 5. proteins; and 6. vitamins. The table on page 567 lists the food substances, their functions, and their sources.

Perhaps this would be a good time for you to review the importance to the living organism of the first four of these substances and their chemical structures, as outlined in Chapter 3.

Water has many uses. ***Water*** is inorganic, and does not yield energy to the tissues. However, it is so vital in the maintenance of life that a person deprived of it dies sooner than he would if deprived of other types of food.

If you weigh 100 pounds, your body contains between 60 and 70 pounds of water. Much of this water is organized into your body protoplasm and into the spaces between the cells. As water is lost, first from the intercellular spaces and then from the cells themselves, the protoplasm becomes more and more solid and finally dies. This water loss is part of the process called ***dehydration.***

The fluid part of blood, called *plasma,* is 91 to 92 percent water. Water is essential in the plasma as a solvent for the food and waste products that are transported to and from the body tissues. Water serves further as a solvent in the movement of dissolved foods from the digestive tract to the blood and in the removal of tissue wastes from the skin and kidneys. The kidneys alone pass two to five pints of excess water daily; this water contains many cellular wastes which the body must eliminate.

The flow of sweat is essential in the regulation of heat loss from the body. ***Evaporation,*** or the change of a substance from a fluid to a gas, requires heat. When perspiration evaporates from the body surface, heat resulting from internal oxidation is lost.

Water requirements of the body are

met in three ways: 1. some water is present in the food you eat; 2. some is a by-product of oxidation in cells; and 3. some is consumed as drinking water. The amount required varies with the temperature and humidity of the air and the amount of body activity.

The importance of mineral salts in the body. Table salt, or *sodium chloride,* is consumed directly and in considerable quantities in the diet. Other salts (chemical compounds composed of a mineral and one or more other elements) are also present in food. Since salts are lost in perspiration, persons exposed to excessive heat over long intervals must either increase the salt in the diet or supplement the normal diet with salt tablets.

Animals require *calcium* and *phosphorus* in greater abundance than other mineral elements. Calcium is necessary for proper functioning of plasma membranes, while phosphorus is a component of ATP, DNA, and RNA. Calcium phosphate is important in the formation of bones and teeth. These two elements form about 5 percent of animal tissue when combined with others in the form of proteins. Milk is an ideal source of these two elements; other sources include whole-grain cereals, meat, and fish. Calcium is also necessary to insure the proper clotting of blood and, together with *magnesium,* to nerve and muscle action. *Potassium* compounds are essential to growth.

Iron compounds are essential for the formation of red blood corpuscles. Meats, green vegetables, and certain fruits such as plums or prunes and raisins are important sources of iron in the diet. *Iodine salts* are essential in the formation of the thyroid gland's secretion. Iodine may be obtained from drinking water or by eating sea foods.

Minerals are vital to the body in many ways. Each of them, however, must be in a compound form before it can be used by the body. Eating chemically pure elements such as sodium or chlorine would be fatal. When these elements are in a compound form, such as sodium chloride, however, they are harmless and in fact essential to the body.

What are organic nutrients? We call carbohydrates, fats, and proteins ***organic nutrients*** because they are originally formed by living cells and contain the element carbon. Carbohydrates and fats supply energy. The tissue-building value of foods cannot be measured except by observing growth in animals when they are fed. But the energy value can be measured in heat units, called *Calories.* A ***Calorie*** (large Calorie) is the amount of heat required to raise the temperature of 1,000 cubic centimeters (about one quart) of water one degree centigrade. This is 1,000 times as great as the small calorie used in physical measurements of heat. Notice that the two are distinguished by the large Calorie capitalizing.

The number of Calories required in an average day's activity varies with the kind of activity and with the age and body build of the person concerned. A daily requirement of 2,500 to 3,500 Calories is probably above average.

More than half of your total diet is carbohydrate food. Regardless of this high percentage, the accumulated carbohydrate reserve in your body is less than one percent of your total weight. This is evidence that carbohydrates are primarily fuel foods, and that they are oxidized rapidly to supply the energy required for body activity.

The significance of carbohydrates in the diet. Many different kinds and forms

FOOD SUBSTANCES

Substance	*Kind of Substance*	*Essential For*	*Source*
Water	Inorganic compound	Composition of protoplasm and blood Dissolving substances	All foods (released during oxidation)
Sodium compounds	Mineral salts	Blood and other body tissues	Table salt, vegetables
Calcium compounds	Mineral salts	Deposition in bones and teeth Heart and nerve action Clotting of blood	Milk, whole-grain cereals, vegetables, meats
Phosphorus compounds	Mineral salts	Deposition in bones and teeth Formation of ATP, nucleic acids	Milk, whole-grain cereals, vegetables, meats
Magnesium	Mineral salts	Muscle and nerve action	Vegetables
Potassium compounds	Mineral salts	Blood and cell activities Growth	Vegetables
Iron compounds	Mineral salts	Formation of red blood corpuscles	Leafy vegetables, liver, meats, raisins, prunes
Iodine	Mineral salts	Secretion by thyroid gland	Sea foods, water, iodized salt
Carbohydrates	Organic nutrients	Energy (stored as fat or glycogen) Bulk in diet	Cereals, bread, pastries, tapioca, fruits, vegetables
Fats	Organic nutrients	Energy (stored as fat or glycogen)	Butter, cream, cheese, oleomargarine, lard, oils, nuts, meats
Proteins	Organic nutrients	Growth, maintenance, and repair of protoplasm	Lean meats, eggs, milk, wheat, beans, peas, cheese
Vitamins	Complex organic substances	Regulation of body processes Prevention of deficiency diseases	Various foods, especially milk, butter, lean meats, fruits, leafy vegetables; also made synthetically

of *carbohydrate* foods are included in the average diet. Some are easily digested and are transported to the tissues with little chemical change. Others require more chemical simplification for tissue use. One group, while indigestible, provides necessary bulk, or roughage, in the diet. All carbohydrates which are digestible reach the body tissues as *glucose,* or dextrose.

Many simple sugars are present in the foods you eat. These include glucose, fructose, and galactose. As you learned in Chapter 3, these sugars are classed as monosaccharides because they consist of single hexose molecules with the chemical formula $C_6H_{12}O_6$. These sugars are quick-energy sources because they require little or no chemical change before they are absorbed by the blood from the digestive organs.

Sucrose (cane sugar), *lactose* (milk sugar) and *maltose* (malt sugar) are disaccharides, composed of two hexose units. These double sugars require digestive action which reduces them to simple sugar molecules for absorption.

Starches, or polysaccharides, compose a large part of the carbohydrate portion of the diet. They are abundant in cereal grains such as wheat, corn, rye, barley, oats, and rice, in addition to potatoes and tapioca.

As you learned in Chapter 3, starches are composed of large chains of glucose units, each represented as $C_6H_{10}O_5$. Starch digestion involves the addition of a water molecule to a glucose unit. Maltose is formed during starch digestion. Later this double sugar is reduced to glucose and absorbed by the blood.

Much of the glucose received by the blood and transported to the liver is converted temporarily to animal starch, or *glycogen.* As glucose is oxidized in the body tissues, glycogen is changed back to glucose (dextrose) and released into the blood stream. In this manner, the level of blood sugar is maintained. Were it not for this action of the liver, we would have to eat a small quantity of carbohydrate foods constantly.

Celluloses are complex carbohydrates present in the cell walls of vegetable foods. These materials cannot be digested in the human system. However, as roughage in the digestive system they expand the intestines and stimulate muscle contractions of the walls resulting in movement of the food content. This muscular activity is necessary for normal digestion.

Fats are highly concentrated energy foods. ***Fats*** and ***oils*** yield more than twice as much energy as carbohydrates. Common sources of these foods in the diet include butter, cream, cheese, oleomargarine, lard and other shortenings, vegetable oils, nuts, and meats.

Fats undergo slow digestion by enzyme influence during digestion. The complex fat molecules are split into molecules of *glycerin* (glycerol) and *fatty acids.* Water molecules combine with fat molecules in the process.

Body fats are formed by the conversion of excess carbohydrates. The chief storehouses of body fat are the tissue spaces beneath the skin, the region of the kidneys, and the liver. Excess body fat is detrimental to health. For this reason both the carbohydrate and fat content of the diet should be carefully regulated.

Proteins and their uses. You learned in Chapter 3 that ***proteins*** are complex organic molecules of almost unlimited chemical structure. They are composed of large numbers of units known as *amino acids.* The proteins you consume as food are foreign to your body and cannot be used in your tissues. However, reduced to amino acids during digestion, they supply the units required by your cells in synthesizing your own specific protein molecules. Both growth and repair of body substances depend on protein intake in your diet.

Certain of the amino acid molecules absorbed by the blood are not used in cell protein synthesis. These are broken down by chemical activity of the liver, called *deamination*, into two parts. One part contains carbon and is sent to the tissues as glucose. The nitrogen-containing part is synthesized as urea, a waste product received by the blood and transported to the kidneys for excretion in the urine. This urea is in addition to that formed during the breakdown of tissue protein.

The most valuable protein sources in the diet include lean meat, eggs (albumen), milk (casein), cheese, whole wheat (gluten), beans, and corn. These are body-building foods, essential in growth during childhood and young adult life and in the maintenance and repair of protoplasm in the mature years.

Vitamins – organic compounds essential to proper body functioning. In 1911 Dr. Casimir Funk found that certain substances, apart from ordinary nutrients, are present in very small amounts in foods. They seemed to be necessary for normal growth and body activity and in the prevention of certain diseases called ***deficiency diseases.*** He called these substances ***vitamins.*** Vitamins were first designated by letters — A, B, C, etc. Later it was discovered that certain vitamins thought to be simple were made up of many different components such as, for example, the vitamin-B complex. Then such names as B_1, B_2, and so forth were adopted. Today most of the vitamins have names that indicate their chemical composition, although letters are still used as a means of easy and simple reference. Vitamins are organic compounds that act as catalysts. In this respect they are similar to the digestive enzymes. The best sources, functions, and deficiency symptoms of the better-known vitamins are summarized in the table on page 570.

Some vitamins may be stored in the body, while others must be supplied constantly because the excess in the diet is excreted in the urine. Vitamin D can be produced in the skin. Other vitamins or their precursors must be supplied by the diet or taken in the form of extracts, if the normal diet lacks them. But the best source of vitamins is a balanced diet.

Synthetic vitamins. Most of the vitamins listed in the table on page 570 may be purchased in highly concentrated synthetic form. These preparations are important in supplementing the natural vitamins of the diet when deficiency occurs. However, even with all the publicity given commercial vitamin preparations, remember that a normal, balanced diet is much more desirable for good health than supplementary doses. Your doctor can diagnose vitamin deficiency and prescribe concentrated vitamins if he thinks you need them. If a proper diet is followed, additional vitamins are probably a waste of money and are unnecessary for the average person.

The phases of digestion. There are two reasons why tissues cannot use most foods in the forms in which you eat them. First, many substances are insoluble in water and could not enter the plasma membranes of the cells even if they reached them. Second, these foods are too chemically complex for tissues to use, either in oxidation or for

FUNCTIONS AND IMPORTANT SOURCES OF VITAMINS

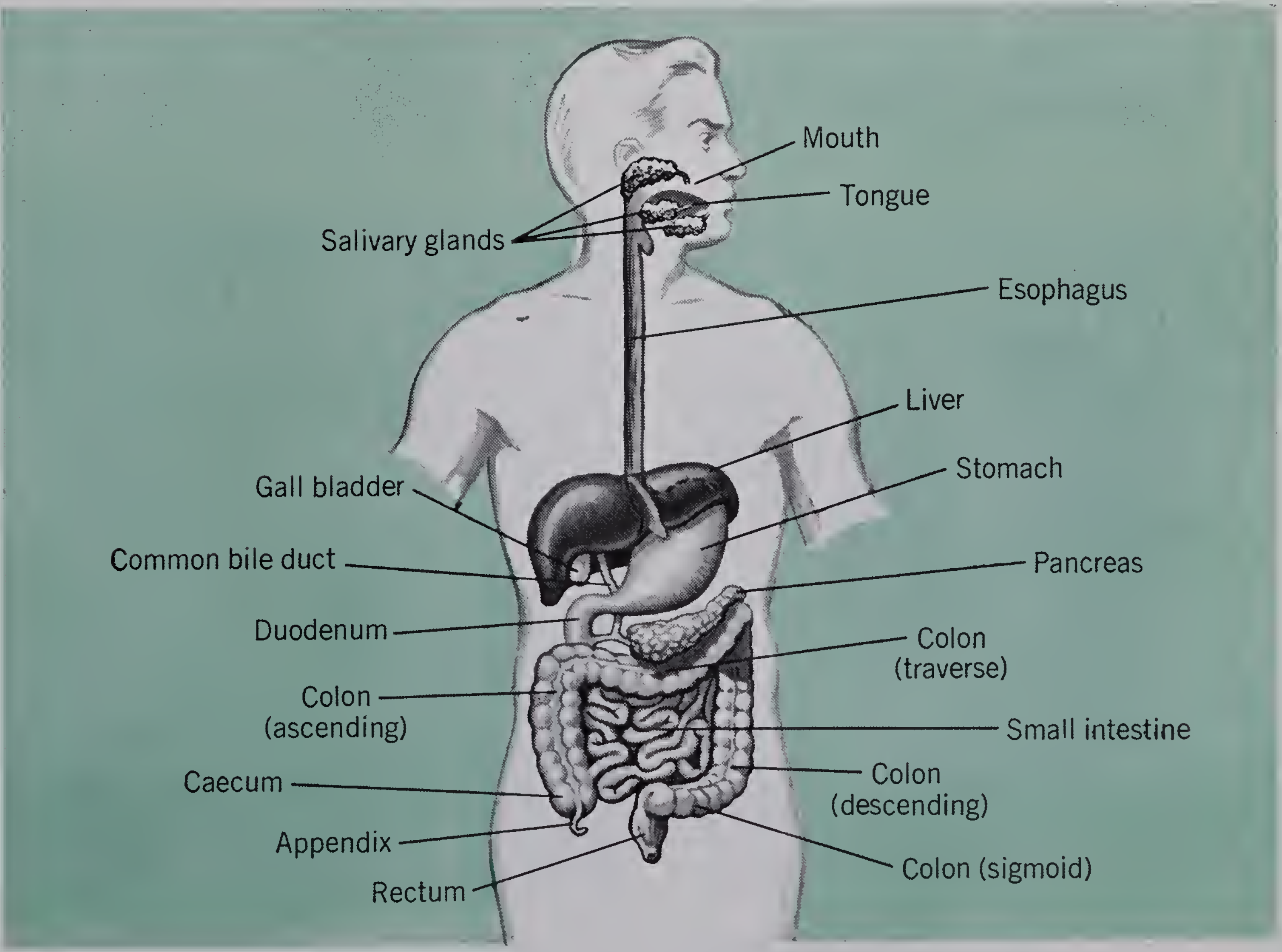
Vitamins	*Best Sources*	*Essential For*	*Deficiency Symptoms*
Vitamin A (oil soluble)	Fish liver oils Liver and kidney Green and yellow vegetables Yellow fruit Tomatoes Butter Egg yolk	Growth Health of the eyes Structure and functions of the cells of the skin and mucous membranes	Retarded growth Night blindness Susceptibility to infections Changes in skin and membranes Defective tooth formation
Thiamin (B_1) (water soluble)	Sea food Meat Soybeans Milk Whole grain Green vegetables Fowl	Growth Carbohydrate metabolism Functioning of the heart, nerves, and muscles	Retarded growth Loss of appetite and weight Nerve disorders Less resistance to fatigue Faulty digestion (beriberi)
Riboflavin (B_2) (water soluble)	Meat Soybeans Milk Green vegetables Eggs Fowl Yeast	Growth Health of the skin and mouth Carbohydrate metabolism Functioning of the eyes	Retarded growth Dimness of vision Inflammation of the tongue Premature aging Intolerance to light
Niacin (water soluble)	Meat Fowl Fish Peanut butter Potatoes Whole grain Tomatoes Leafy vegetables	Growth Carbohydrate metabolism Functioning of the stomach and intestines Functioning of the nervous system	Smoothness of the tongue Skin eruptions Digestive disturbances Mental disorders (pellagra)
Vitamin B_{12} (water soluble)	Green vegetables Liver	Preventing pernicious anemia	A reduction in number of red blood cells
Ascorbic acid (C) (water soluble)	Citrus fruit Other fruit Tomatoes Leafy vegetables	Growth Maintaining strength of the blood vessels Teeth development Gum health	Sore gums Hemorrhages around the bones Tendency to bruise easily (scurvy)
Vitamin D (oil soluble)	Fish liver oil Liver Fortified milk Eggs Irradiated foods	Growth Regulating calcium and phosphorus metabolism Building and maintaining bones, teeth	Soft bones Poor teeth development Dental decay (rickets)
Tocopherol (E) (oil soluble)	Wheat-germ oil Leafy vegetables Milk Butter	Normal reproduction	Undetermined
Vitamin K (oil soluble)	Green vegetables Soybean oil Tomatoes	Normal clotting of the blood Normal liver functions	Hemorrhages

growth and repair by protein synthesis. Digestion brings about changes in both of these conditions, with the result that cells can absorb and use the products. Thus in ***digestion*** complex foods are broken down into smaller molecules of water-soluble substances that may be used by the body cells.

The first part of the change that occurs during digestion is *mechanical.* This phase involves the chewing of food in the mouth, and the constant churning and mixing action brought about by the muscular movement of the walls of the digestive organs. The breakdown of food into small particles and the thorough mixing with various juices aid the second phase of digestion, which is *chemical.* This phase is accomplished by digestive enzymes that are present in various secretions produced by the digestive glands. In studying the entire process of digestion, you will find it helpful to refer to the "Trans-Vision" of the human torso between pages 584 and 585.

The digestive system includes the organs that form the ***alimentary canal,*** or food tube (Fig. 41–1). It also includes those organs that do not actually receive undigested food, but that act on foods in the alimentary canal by means of secretions delivered to it by various ducts. *Ducts* are tubes extending from certain glands into the digestive organs.

The mouth – the first digestive structure. The mouth is an organ of sensation and of speech, but its chief function is to prepare food for digestion. The ***hard palate*** forms the roof of the mouth in the chewing area. It consists of a bony structure covered with several membranes. The ***soft palate*** lies just back of the hard palate. It is formed


Mouth
Tongue
Salivary glands
Esophagus
Liver
Stomach
Gall bladder
Common bile duct
Pancreas
Duodenum
Colon (traverse)
Colon (ascending)
Small intestine
Caecum
Colon (descending)
Appendix
Colon (sigmoid)
Rectum

41-1 The organs of digestion in the human body.

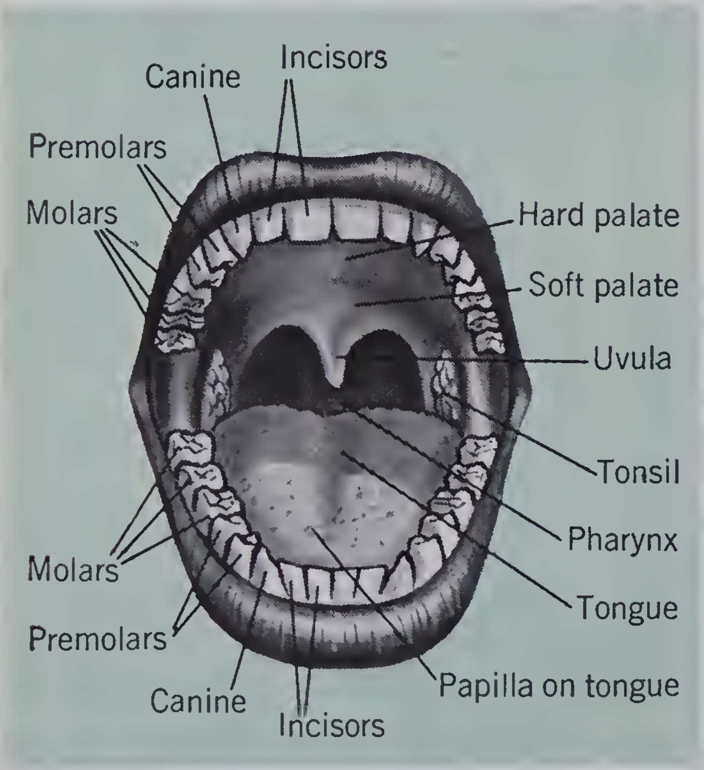
by folded membranes that extend from the rear portion of the hard palate and fasten along the sides of the tongue. You can see a knoblike extension of the soft palate called the ***uvula*** (*yu*-vyu-la) when the mouth is opened wide (Fig. 41–2).

The back of the mouth opens into a muscular cavity called the ***pharynx*** (*fair*-inks). This cavity extends upward, above the soft palate, to the nasal cavity. The soft palate partly separates the nasal cavity from the mouth cavity and extends into the pharynx, somewhat like a curtain, as you can see in Fig. 41–2. The inside of the cheeks forms the side walls of the mouth cavity. The cheek linings are mucous membranes, containing numerous mucous glands. ***Mucus***, a lubricating secretion, mixes with food in the mouth and aids in chewing and swallowing. The lining of the mouth turns outward to form the lips.

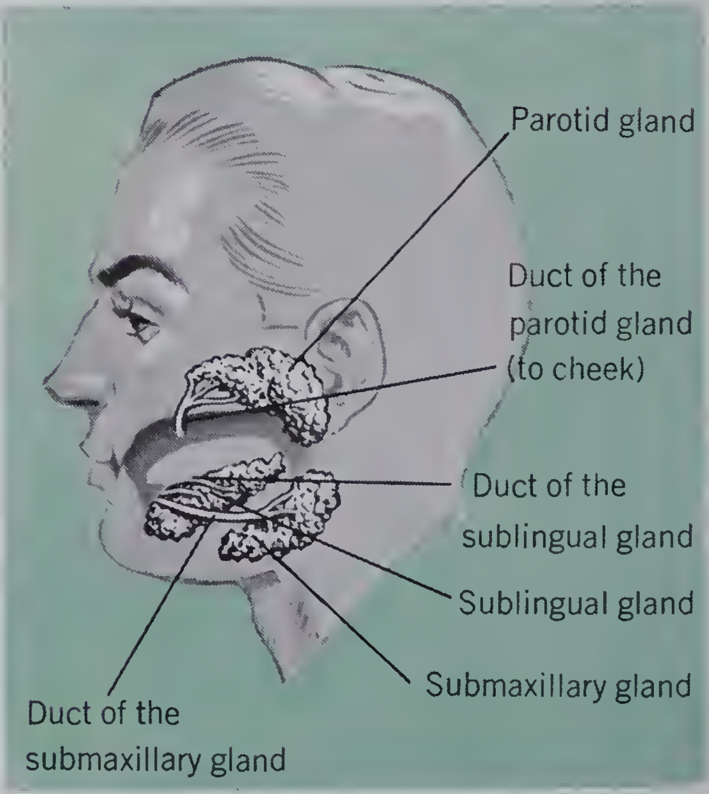
The salivary glands. The *parotid glands* are the largest of the ***salivary glands.*** One lies on each side of the face below and in front of the ears. Ducts from these glands empty ***saliva*** into the mouth, opposite the second upper molars. An infection of the parotid glands, causing swelling and irritation, is the disease called *mumps.* The *submaxillary glands* lie within the angles of the lower jaws. The *sublingual glands* are embedded in the mucous membranes in the floor of the mouth, under the tongue (Fig. 41–3). Ducts from both of these glands open into the floor of the mouth under the tongue. The smell of food, the sight of it, the presence of it in the mouth, and the taste of it stimulate the secretion of saliva. In other words your mouth "waters."

The tongue and its functions. The tongue lies in the floor of the mouth and extends into the throat. This muscular organ performs several different functions, as follows:

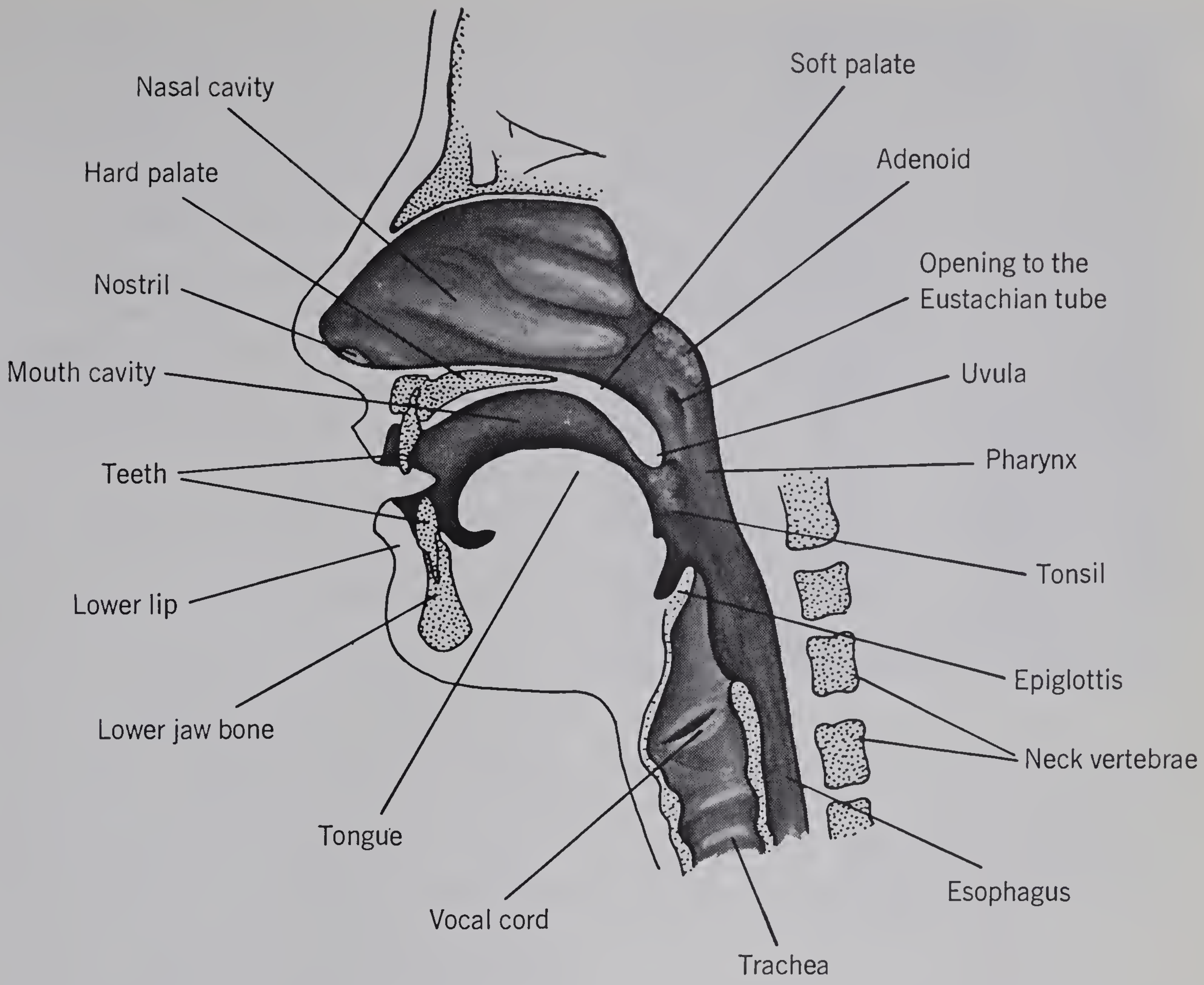
1. It acts as an organ of taste. Scattered over the surface of the tongue are numerous tiny projections. These pro-


Canine
Incisors
Premolars
Molars
Hard palate
Soft palate
Uvula
Tonsil
Pharynx
Tongue
Papilla on tongue
Molars
Premolars
Canine
Incisors

41-2 Digestion begins in the mouth, the most anterior organ of the alimentary canal.


Parotid gland
Duct of the parotid gland (to cheek)
Duct of the sublingual gland
Sublingual gland
Submaxillary gland
Duct of the submaxillary gland

41-3 Three pairs of salivary glands secrete saliva into the mouth.


Nasal cavity
Hard palate
Nostril
Mouth cavity
Teeth
Lower lip
Lower jaw bone
Tongue
Vocal cord
Trachea
Soft palate
Adenoid
Opening to the Eustachian tube
Uvula
Pharynx
Tonsil
Epiglottis
Neck vertebrae
Esophagus

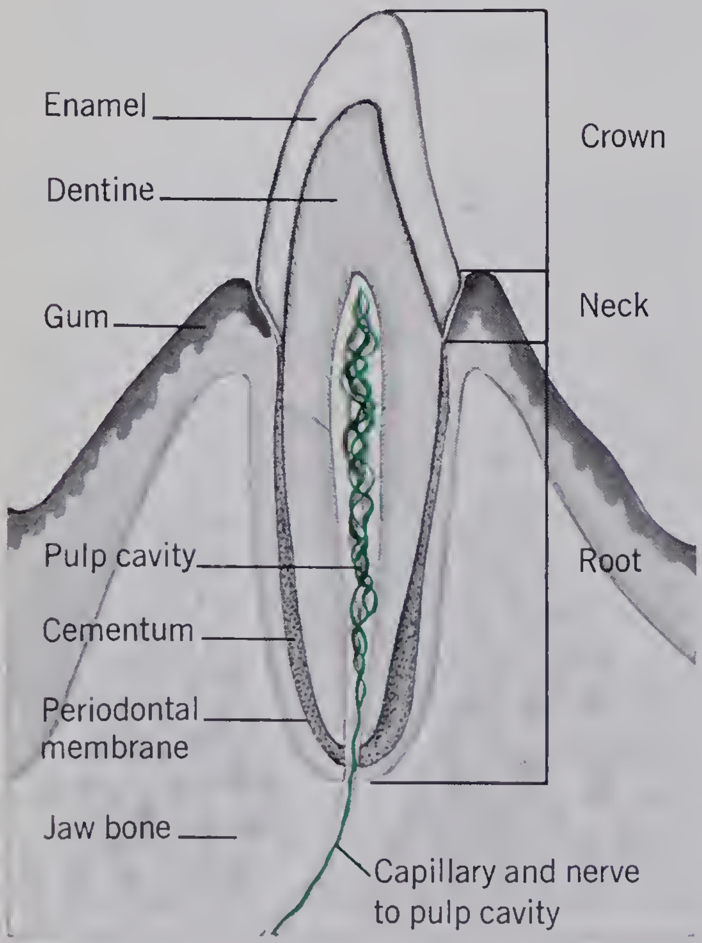
41-4 This cutaway diagram shows the internal structure of the mouth and throat.

jections contain ***taste buds***, which have nerve endings at their base. When food is mixed with mucus and saliva, it makes contact with the taste buds, thus stimulating the nerve endings.

2. The tongue aids in chewing by keeping the food between the teeth.
3. During swallowing, food is worked to the back of the tongue. When the tongue is jerked downward, food lodges in the pharynx and passes into the esophagus opening. The opening of the trachea is closed by the pressure of the tongue and breathing ceases for a moment during the process of swallowing.
4. The tongue keeps the inner surface of the teeth clean, because you roll it around in your mouth.
5. The tongue is essential in speech. In forming certain word sounds, the tongue acts together with the lips, teeth, and hard palate. Without such interaction these sounds could not be formed into words.

The types of teeth. If you start between the two front teeth and count back, your permanent teeth are arranged in the following order: the first two are the flat *incisors*, with sharp edges for cutting food (Fig. 41–2). Next, near the corner of your lips, is a large conical *canine*, or cuspid, tooth. These teeth are often called eye teeth, although they have no connection with the eyes. Behind the canine teeth are two *premolars,* or bicuspids. Next come three *molars* (two, if you have not cut your wisdom teeth). The premolars and molars have flat surfaces and are adapted for grinding and crushing. Many jaws are too small to provide space for the third molars, or wisdom teeth. In such jaws they may grow in crooked, lodge against the second molars, or remain impacted.

The structure of the teeth. A tooth is composed of three general regions. The exposed portion above the gum line is called the *crown.* A narrow portion at the gum line is called the *neck,* while the *root* is encased in a socket in the jawbone and holds the tooth securely in place. Roots vary in form in the different kinds of teeth. They may be long and single, or they may consist of two, three, or four projections. The crown is covered with a hard white substance, the *enamel.* The covering of the root is called *cementum,* which holds the tooth firmly together. The root is anchored firmly in the jaw socket by the fibrous *periodontal membrane.*



41-5 This vertical section through a canine tooth shows the various parts.

If you cut a tooth lengthwise, you can see the *dentine* beneath the protective layers of enamel and cement (Fig. 41–5). Dentine is a softer substance than enamel and forms the bulk of the tooth. The *pulp cavity* lies inside the dentine area.

The structure of the esophagus and stomach. After a food mass is ground between the teeth, rolled on the tongue, and mixed with saliva, it passes through the pharynx to the ***esophagus.*** This is a tube about a foot long that connects the mouth to the stomach. Food travels to the stomach with the aid of layers of smooth muscle in the wall of the esophagus. One layer is circular and squeezes inward. The other layer is longitudinal and contracts in a wave that travels downward, pushing the food ahead of it.

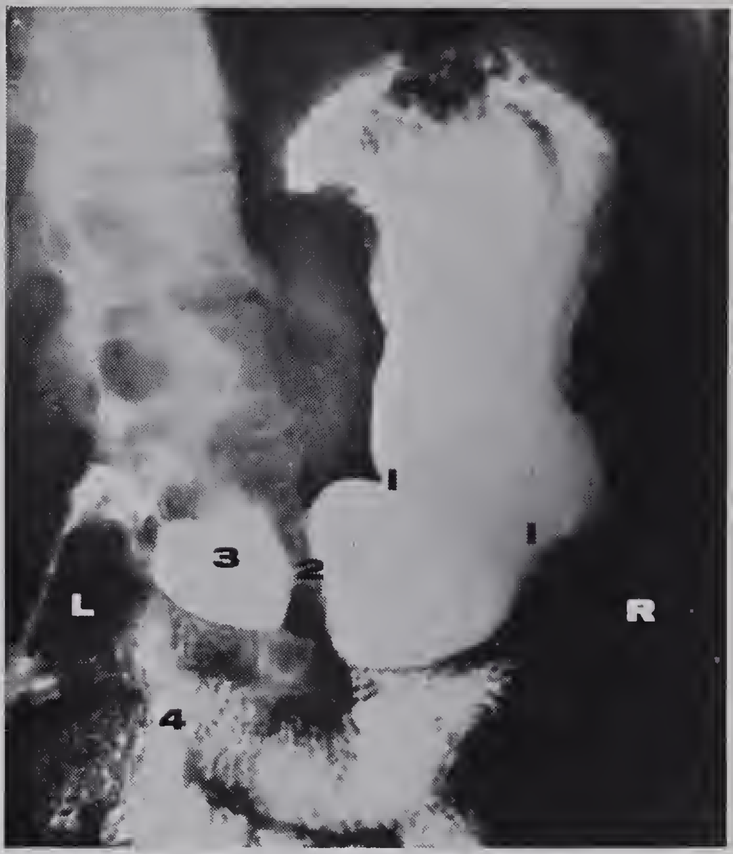
The ***stomach*** lies in the upper left region of the abdominal cavity just below the diaphragm. The stomach walls contain three layers of smooth muscle, each arranged differently. One layer is longitudinal, one is circular, and one is angled, or oblique. Contraction of the smooth muscle fibers of the various layers in different directions causes a twisting, squeezing, and churning movement of the stomach.

The lining of the stomach is a thick, wrinkled membrane in which numerous ***gastric glands*** are embedded. Each of these glands is a tiny tube with an opening that leads into the stomach. The walls of each gland are lined with secretory cells. There are three kinds of glands. One kind secretes an enzyme; a second secretes hydrochloric acid; and a third mucus. Together these secretions form ***gastric fluid,*** which passes directly into the stomach.

Food usually remains in the stomach two to three hours. During this period rhythmic contractions of the stomach muscles churn the food back and forth in a circular path. This action separates the food particles and mixes them thoroughly with the stomach secretions. At the completion of stomach digestion, the valve at the intestinal end, the ***pyloric valve,*** opens and closes several times. With each opening of the valve, food moves into the small intestine. Finally the stomach is relieved of its contents and begins a period of rest. After several hours without food, contractions start again and cause the sensation of hunger.

The small intestine. When food leaves the stomach through the pyloric valve, it enters the ***small intestine,*** a tube about one inch in diameter and 23 feet long. This part of the alimentary canal is the most vital of all digestive organs. The upper ten inches of the small intestine are referred to as the *duodenum* (doo-oh-*dee*-num). The duodenum curves upward, then backward and to the right, beneath the liver. Beyond the duodenum is a second and much longer region, the *jejunum.* This portion, about seven feet long, is less coiled than the other regions. The lower portion of the small intestine is referred to as the *ileum,* which is about 15 feet long and coils through the abdominal cavity before joining the large intestine.

Embedded in the mucous lining of the small intestine are many tiny ***intestinal glands.*** These glands secrete ***intestinal fluid,*** containing four enzymes, which passes into the small intestine.



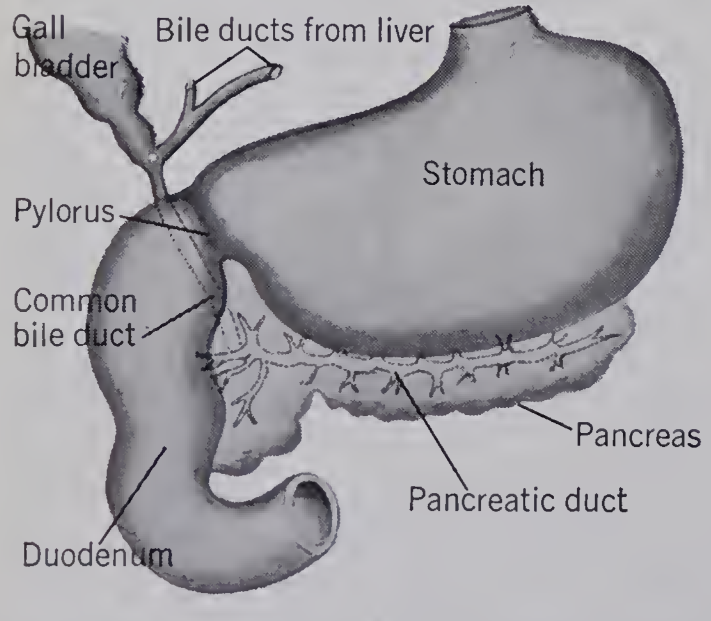
41-6 This X-ray photograph is of a normal stomach that has been filled with barium to make the various parts visible on film. Note contractions (1); pyloric valve (2); beginning of small intestine (3); and region of villi in the small intestine (4). R indicates right side; L indicates left side.

The liver — the largest gland in the body. The ***liver*** weighs about three and a half pounds and is a dark chocolate color. It lies in the upper right region of the abdominal cavity and secretes ***bile.*** Bile is a brownish-green fluid which passes from the liver through a series of *bile ducts* forming a Y. As bile is secreted in the liver, it passes down one branch of the Y, then travels up the other branch to the ***gallbladder.*** Here the bile is stored and concentrated as part of the water is removed. The base of the Y is the common bile duct, which carries bile from the gallbladder to the duodenum. If the common bile duct becomes clogged by a gallstone, or a plug of mucus, bile enters the blood stream and causes a yellowing of the eyes and skin, known as *jaundice.*

The pancreas and pancreatic fluid. The ***pancreas*** is a many-lobed, long, whitish gland, quite similar in general appearance to a salivary gland. It lies behind the stomach and the upper end of the small intestine, against the back wall of the abdominal cavity, and it performs two entirely different functions. The production of insulin by the pancreas will be discussed in Chapter 46. ***Pancreatic fluid,*** a digestive secretion, passes into the small intestine through the *pancreatic duct,* which leads to a common opening with the bile duct in the wall of the duodenum.

The large intestine, or colon. The small intestine ends at a junction with the large intestine, or ***colon,*** in the lower right region of the abdominal cavity. Below the point of junction is a blind end of the large intestine called the ***caecum*** (*see*-kum). The ***vermiform appendix*** is a fingerlike outgrowth of the caecum. Appendicitis is an inflamed condition of the appendix resulting from infection.

The colon is usually five to six feet long and about three inches in diameter. It forms an inverted U in the abdominal cavity. The *ascending colon* runs upward along the right side, where it curves abruptly to the left to form the *transverse colon.* This portion extends across the upper region of the abdominal cavity. Another curve leads to the *descending colon* on the left side. At its lower end the descending colon forms an S, called the *sigmoid colon.* The ***rectum*** is a muscular cavity at the end of the large intestine. The lower end of the rectum forms the ***anal opening.*** A valvelike muscle in the lower end of the rectum controls the elimination of intestinal waste.



41-7 This diagram shows the stomach, pancreas, gall bladder, and duodenum.

The chemical phases of digestion. As foods move through the organs of the alimentary canal, a series of chemical changes occurs in the step-by-step process of simplification. Each of these changes requires a specific enzyme in a digestive secretion. The chemical changes generally involve hydrolysis, since water molecules interact with molecules of the various food materials. Digestive enzymes are therefore hydrolytic enzymes, each associated with the splitting of specific molecules. Digestion in the alimentary canal is necessarily extracellular. That is, enzymatic action takes place outside the cells rather than inside, as in some other forms.

Digestion in the mouth. The chemical action on food begins in the mouth where an enzyme in saliva begins the hydrolysis of starch. Saliva is a thin, alkaline secretion of the salivary glands. It is more than 95 percent water and contains mineral salts, lubricating mucus, and the enzyme *ptyalin* (*ty*-a-lin), sometimes called *salivary amylase* (*am*-i-layze). This enzyme converts cooked starch to maltose, a disaccharide. It is necessary to cook starchy foods such as potatoes to burst the cellulose cell walls. This allows the ptyalin to contact the starch grains. Because of the short time food is in the mouth, starch digestion is seldom completed when food is swallowed. However, ptyalin continues its action in the stomach.

The action of gastric fluid. The principal enzyme in gastric fluid is *pepsin,* sometimes referred to as *gastric protease.* This enzyme acts on protein, splitting the complex molecules into simpler groups of amino acids known as *peptones* and *proteoses.* This is the first in a series of chemical changes involved in protein digestion.

Hydrochloric acid, in addition to providing the proper medium for the action of pepsin, dissolves insoluble minerals and kills many bacteria that enter the stomach with food. It also regulates the action of the pyloric valve, which opens at the completion of stomach digestion and allows food to pass to the small intestine.

The food passing from the stomach to the small intestine contains the following: 1. fats, unchanged; 2. sugars, unchanged; 3. the starches that were not acted on by ptyalin; 4. maltose formed by the action of ptyalin; 5. coagulated milk casein; 6. those proteins that were unchanged by the pepsin of the gastric fluid; and 7. peptones and proteoses formed from pepsin acting on protein.

Functions of the liver and bile. The liver performs several vital functions. In receiving glucose from the blood and changing it to glycogen, it serves as a chemical factory. It serves also as a storehouse in holding reserve carbohydrates as glycogen. In acting on amino acids and forming urea, it is an organ of excretion.

As a digestive gland, the liver secretes bile, which acts on food in the small intestine. In the formation of bile, the liver plays a part in using what might otherwise be discarded as waste. Part of the bile is formed from worn-out hemoglobin that the blood system can no longer use. Bile has the following important functions:

1. It is partially a waste substance containing material from dead red blood corpuscles filtered from the blood stream by the liver.
2. It increases the digestive action of lipase, an enzyme produced in the pancreas, by breaking globules of fat into small droplets.

Actually, bile is not a digestive secretion. In splitting large fat particles into smaller ones, a milky colloid called an *emulsion* is produced. In this form pancreatic fluid can act on fats more readily.

The role of the pancreas in digestion. Pancreatic fluid acts on all three classes of organic nutrients. Pancreatic fluid contains the following three enzymes: 1. *trypsin;* 2. *amylase;* and 3. *lipase* (*lyp*-ays). Trypsin continues the breakdown of proteins that began in the stomach by changing peptones and proteoses to still simpler amino acid groups called *peptides.* In addition, trypsin may act on proteins that were not simplified during digestion in the stomach. Peptides are not the final product of protein digestion, because one additional step is necessary to form the amino acids used in protein synthesis by the cells. Amylase duplicates the action of the ptyalin in saliva by changing starch into maltose. This is how the potatoes you did not chew enough are changed to sugar. Lipase splits fat into *fatty acids* and *glycerin,* both of which can be absorbed by the body cells.

Digestion in the small intestine. The intestinal fluid secreted by the intestinal glands is highly alkaline and contains four principal enzymes: 1. *erepsin;* 2. *maltase;* 3. *lactase;* and 4. *sucrase.* Erepsin completes protein digestion by changing peptides, formed by the pancreatic fluid, to amino acids. Maltase splits the disaccharide maltose into the

SUMMARY OF DIGESTION

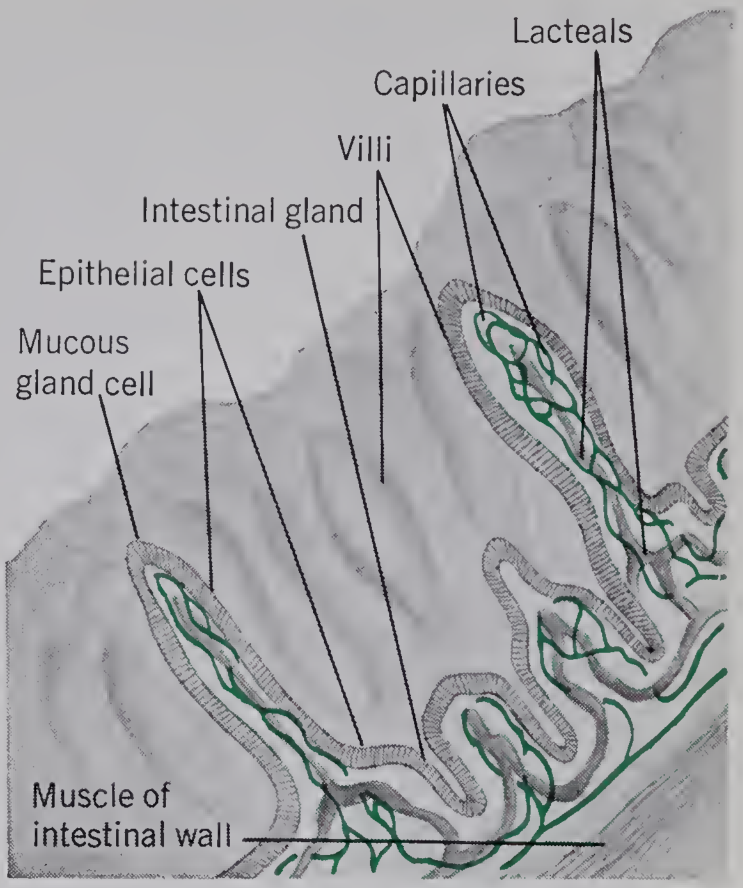
Place of Digestion	*Glands*	*Secretion*	*Enzymes*	*Digestive Activity*
Mouth	Salivary	Saliva	Ptyalin	Changes starch to maltose, lubricates
	Mucous	Mucus		Lubricates
Esophagus	Mucous	Mucus		Lubricates
Stomach	Gastric	Gastric fluid	Pepsin	Changes proteins to peptones and proteoses
		Hydrochloric acid		Activates pepsin Dissolves minerals Kills bacteria
	Mucous	Mucus		Lubricates
Small intestine	Liver	Bile		Emulsifies fats Activates lipase
	Pancreas	Pancreatic fluid	Trypsin	Changes proteins, peptones, and proteoses to peptids
			Amylase	Changes starch to maltose
			Lipase	Changes fats to fatty acids and glycerin
	Intestinal glands	Intestinal fluid	Erepsin	Changes peptids to amino acids
			Maltase	Changes maltose to glucose
			Lactase	Changes lactose to glucose and galactose
			Sucrase	Changes sucrose to glucose and fructose
	Mucous	Mucus		Lubricates
Large intestine (colon)	Mucous	Mucus		Lubricates

monosaccharide glucose, the final product of carbohydrate digestion. Lactase has a similar action on lactose, or milk sugar, in changing it to glucose and galactose. Sucrase acts on sucrose and changes it to the simple sugars glucose and fructose.

Thus, with the combined action of bile, pancreatic fluid, and intestinal fluid in the small intestine, all three classes of foods are completely digested. As soluble substances in the form of simple sugars, fatty acids and glycerin, and amino acids, they leave the digestive system and enter the blood and lymph.

Absorption in the small intestine. A magnified portion of the small intestine shows that its irregular lining gives rise to great numbers of fingerlike projections

41-8 The villi greatly increase the absorption surface in the small intestine.



called ***villi.*** These projections are so numerous that they give a velvety appearance to the intestinal lining. Within the villi are branching lymph vessels called *lacteals* and *blood vessels* (Fig. 41–8). The villi bring blood and lymph close to the digested food and increase the absorption surface of the intestine enormously. Absorption is increased further by a constant swaying motion of the villi through the intestinal content.

Glycerin and fatty acids enter the villi and are carried away by the lymph. They eventually reach the general circulation and travel to the tissues. Glucose and amino acids, however, enter the blood vessels of the villi. From the villi they are carried directly to the liver through the portal vein.

Water absorption in the large intestine. The large intestine receives a watery mass of undigestible food bulk from the small intestine. As this mass progresses through the colon, much of the water is absorbed and taken into the tissues. The remaining intestinal content, or ***feces*** (*fee*-ses), becomes more solid as the water is absorbed. The feces pass into the rectum, from which they are eventually eliminated through the anal opening.

The chart at the left summarizes the digestive processes occurring in the various organs.

IN CONCLUSION

Food is any substance which, when absorbed into the body tissues, yields materials for the production of energy, the growth and repair of tissue, and the regulation of life processes, without harming the organism. Six classes of substances meet the requirements of this definition: water, minerals, carbohydrates, fats, proteins, and vitamins.

The digestive system is a tube divided into various regions. Each particular region of the tube is a specialized organ adapted for carrying on certain phases of the digestive process. Many glands pour their enzymatic secretions into the digestive tract. These enzymes bring about the chemical changes in foods, while muscular contractions bring about the mechanical changes.

In the next chapter we shall investigate the way digested food is transported in the body. We shall also study the way in which waste materials are excreted by means of the kidneys and skin.

BIOLOGICALLY SPEAKING

alimentary canal
amylase
anal opening
bile
caecum
Calorie
colon
deficiency diseases
dehydration
digestion
duodenum
esophagus
evaporation
feces
gallbladder
gastric fluid
gastric gland
hard palate
intestinal fluid
intestinal gland
liver
mucus
organic nutrients
pancreas
pancreatic fluid
pharynx
pyloric valve
rectum
saliva
salivary glands
soft palate
taste buds
uvula
vermiform appendix
villi
vitamins

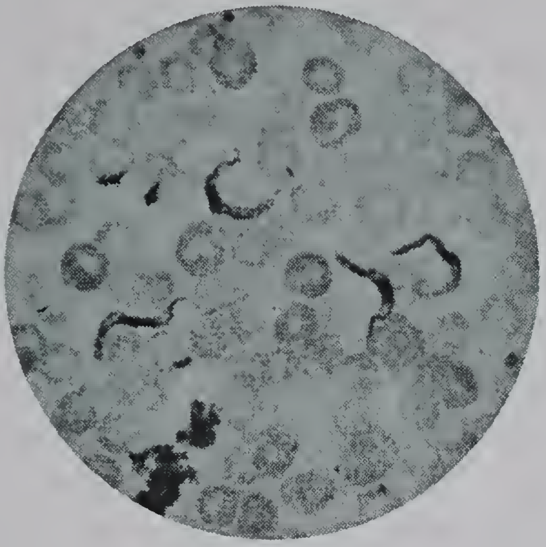
QUESTIONS FOR REVIEW

1. List six classes of foods and the general use of each in the body.
2. In what two general ways must foods be changed during digestion?
3. List, in order, the divisions of the alimentary canal.
4. Discuss five or more ways in which the tongue is used.
5. Name and locate the various salivary glands.
6. Name the regions that can be distinguished in a tooth cut lengthwise.
7. Why is it especially important that you chew bread and potatoes thoroughly?
8. Suppose that a person had a glass of milk and a sandwich consisting of bread, butter, and ham. Tell what would happen to each of these foods as they go through the process of digestion.
9. List four functions of bile.
10. Name two important functions of the large intestine.

APPLYING PRINCIPLES AND CONCEPTS

1. Explain how a vitamin deficiency is possible even if an adequate amount of all the vitamins is taken daily.
2. Why is food acid in the stomach and alkaline in the small intestine?
3. Explain how interference with the rhythmic waves of the walls of the large intestine may cause either constipation or diarrhea.
4. Why is it easier to digest sour milk than fresh milk?

CHAPTER 42



TRANSPORT AND EXCRETION

The circulatory system. The flow of nutritive fluids, waste materials, and water in living organisms is called ***circulation.*** The sponges accomplish circulation by literally pumping the ocean into their bodies! The sea water supplies each cell with its individual oxygen needs and washes its wastes away. Actually the cells in man's body are bathed in a fluid with a salt content very much like sea water. We call this solution ***tissue fluid.*** However, man's circulatory system is far more complex than that of the invertebrates. Man produces his own "sea water" and adds other vital substances to it. Then it is piped through his body and circulated with a pump — the heart. If the pump stops working, man's cells are in the same predicament that a sponge would be if thrown up on the beach.

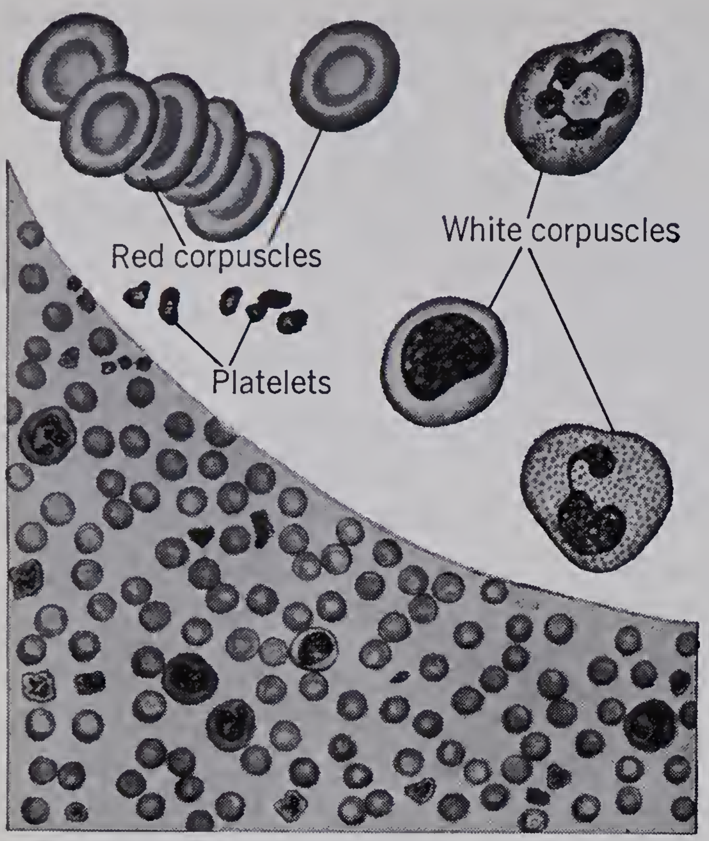
Blood — a fluid tissue. *Blood* is a peculiar type of connective tissue in that the cells are scattered among the nonliving substances composing the fluid portion. The average person has about 12 pints of blood, which composes about 9 percent of the body weight. The fluid portion of the blood is the ***plasma,*** and the blood cells are called the ***solid components.***

If you remove the cells from whole blood, the straw-colored, sticky plasma remains. Nine-tenths of plasma is water. The proteins in plasma give it the sticky quality. One of them, *fibrinogen* (fy-*brin*-o-jen), is essential in the clotting of blood. When fibrinogen is removed from plasma, two other groups of proteins remain. One is *serum albumin,* which is necessary to normal blood and tissue relationships during absorption. The other is *serum globulin,* which gives rise to antibodies that provide immunity to various diseases. *Prothrombin* (proh-*thrahm*-bin), an enzyme found in plasma, is produced in the liver when vitamin K is present in the body. It is inactive normally, but active during clotting.

The following additional materials are also present in plasma:

Inorganic minerals, dissolved in water, give plasma a salt content of approximately 1 percent, while that of sea water is approximately 3 percent. These compounds include carbonates, chlorides, and phosphates of the elements calcium, sodium, magnesium, and potassium. They are absolutely essential to the blood and to the normal functioning of body tissues. Without calcium compounds, blood will not clot in a wound.

Digested foods are present in plasma in the form of glucose, fatty acids and glycerin, and amino acids. These are transported to the liver and other places of storage and to the body tissues.



42-1 The solid components of the blood include red corpuscles, white corpuscles, and platelets.

Nitrogenous (ny-*trahj*-i-nus) *wastes*, resulting from protein metabolism in tissues, and *urea*, produced largely in the liver during the breakdown of amino acids, travel in the plasma to the organs of excretion.

The solid components of blood. The red blood corpuscles (red blood cells, or erythrocytes), the white corpuscles (white blood cells, or leucocytes), and the platelets (thrombocytes) are the three solid components of blood (Fig. 42–1). The ***red corpuscles*** are shaped like disks with both sides concave. Sometimes they travel in the blood in rows that resemble stacks of coins, although they may separate and float individually. The red cells are so small that ten million of them can be spread in one square inch. They are so numerous that, placed side by side, they would cover an area of 3,500 square yards. It is estimated that the blood of a normal person contains 25 trillion red blood cells, or enough to go around the earth four times at the equator, if they were laid side by side. The pigment in the red blood cell is ***hemoglobin.*** This protein substance gives blood its red color and is essential to life.

The red blood cells are produced in the red marrow of bones. During their development they have nuclei, as do all other cells. Normally, by the time they are ready to be released into the blood stream, they have lost these nuclei. The average life span of a red corpuscle is 20 to 120 days. Worn-out red cells are filtered out of the blood in the spleen and liver. At the same time certain valuable compounds are released into the blood stream and used in the manufacture of new red blood cells.

What do the red blood cells do? The hemoglobin within the cell membrane of the red blood cell is a complex protein containing iron. This element gives hemoglobin the ability to carry oxygen. Perhaps you have seen an iron nail turn red with rust. It has oxidized, which means that it has combined with the oxygen in the air. The iron of hemoglobin combines with oxygen in the lungs. But there is an important difference. The iron of the rusty nail does not easily give up its oxygen. The iron in hemoglobin, however, gives up its oxygen at the proper time and place in the body. In this form the hemoglobin is a bright red color and is called *oxyhemoglobin.* Oxygen is carried from the lungs to the tissues in this form. In the tissues the pigment gives up its oxygen. The carbon dioxide formed in the tissues now combines with the hemoglobin, and the product is called *carbhemoglobin.* In this form much of the carbon dioxide is carried to the lungs where it is released, and the cycle is repeated.

The white blood cells. ***White corpuscles*** are on the average larger than red blood cells and differ from them in three ways: 1. White corpuscles have nuclei. 2. White corpuscles do not contain hemoglobin and are therefore nearly colorless. 3. Some white corpuscles can move much like the ameba. The white blood cells are less numerous than the red cells, the ratio being about one white cell to every 600 red cells. White corpuscles are formed in the red bone marrow and in the lymph glands. Normally there are about 8,000 white corpuscles in one cubic millimeter of blood as against four and a half to five million red cells.

The white blood cells that can move about are able to ooze through the capillary walls into the tissue spaces. Here they engulf solid materials, including bacteria, and thus are an important defense of the body against infection. Whenever an infection develops in the tissues, the white-cell count may go from 8,000 to more than 25,000 per cubic millimeter. White corpuscles collect in the area of an infection and destroy bacteria. The remains of dead bacteria, white corpuscles, and tissue fluid is *pus*.

SUMMARY OF COMPOSITION OF BLOOD

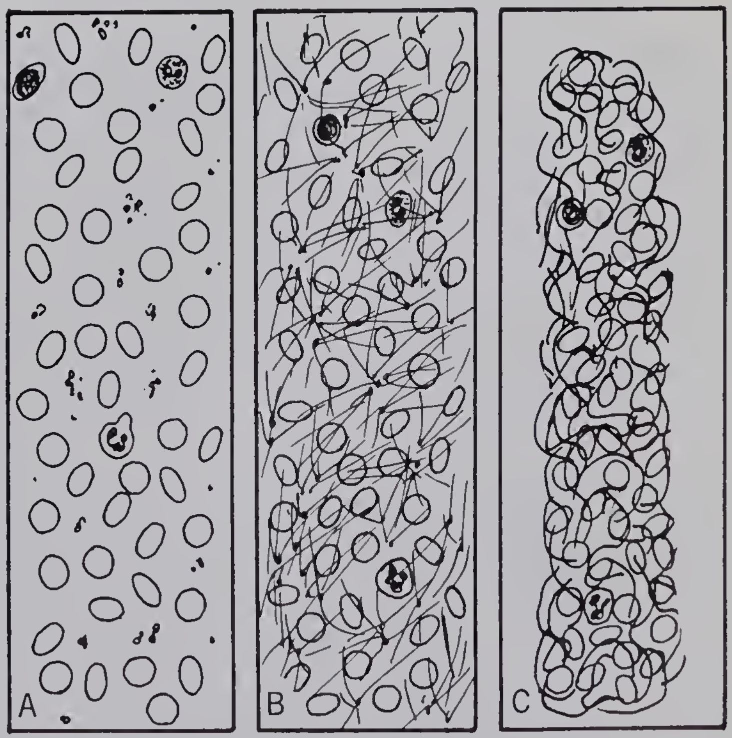
Plasma	*Solid Components*
Water	Red corpuscles
Proteins	White corpuscles
Fibrinogen	Platelets
Serum albumin, globulin	
Digested foods	
Mineral salts	
Organic nutrients	
Cell wastes	

Platelets are irregularly shaped, colorless bodies, much smaller than the red corpuscles. They are probably formed in the red bone marrow. Platelets are not capable of moving on their own but float along in the blood stream. They have an important function in the formation of a blood clot.

Blood is the transporting medium for all body substances. Its functions are shown in the table on page 586.

How blood clots. When you cut small blood vessels in a minor wound, blood oozes out. Such an injury is not alarming because a clot will soon form and the blood flow will stop. You probably take this for granted, without considering what would happen if the flow did not stop.

Clotting results from chemical and physical changes in the blood. When blood leaves a vessel, the platelets disintegrate and release *thromboplastin*. This substance reacts with *prothrombin* and with *calcium* to form *thrombin*.



42-2 This diagram shows the microscopic changes which occur during the clotting of blood. A: before clotting begins; B: formation of threads of fibrin; C: shortening of the fibrin threads and trapping of the blood cells.

Description of the Anatomical Transparencies

Plate 1. This view shows the skin and muscle walls of the front of the body removed from the figure on the opposite page. You are looking at the inner side of the front half of the chest and abdominal cavities. The muscles in the neck, including the sterno-mastoid (1), which turns the head, and the pectoral muscles (2) of the chest, have been sectioned with the ribs (3) and clavicles (4). You are seeing the inside of the sternum (5) to which the rib cartilages (6) attach. The pleural membrane (7) lining the chest cavity is intact on the left side of the figure and has been removed on the right side to show the intercostal muscles (8) between the ribs. The diaphragm (9), a dome-shaped muscle, divides the chest and abdominal cavities. The abdominal cavity is lined with a membrane, the peritoneum (10), which is shown on the left side. It has been removed on the right side to expose the transverse abdominal muscle (11) and the vertical rectus muscle (12), which is partially enclosed in tendonous sheaths (13) pierced by the umbilicus (14).

Plate 2. In this view, most of the skin has been removed from the head to show the temporal (15) and masseter (16) chewing muscles attached to the skull and the large parotid salivary gland (17) with its duct. Around the mouth are the muscles of facial expression. The neck muscles have been removed to expose the thyroid cartilage (18) surrounding the larynx, the thyroid gland (19), the carotid artery, and the internal jugular vein. The numerous veins of the arms and legs lying close to the skin are shown in this view. With the front portion of the pleural membrane (7) removed, the lobes of the lungs (20) and the pericardium (21) covering the heart are visible. Below the diaphragm (9), in the abdominal cavity, are the organs of digestion. On the right side are the liver (22) and gall bladder (23). The stomach (24) is on the left side. The ascending, transverse, and descending regions of the colon (25) surround loops of the small intestine (26).

Plate 3. In this view, the head is sectioned along the midline and you are looking toward the inside of the right half of the cranial cavity (29) and the spinal canal (30) with its dural lining intact. On the side wall of the nasal cavity (31) are the three nasal turbinates. Two sectioned nasal sinuses are above the nasal cavity. The sectioned tongue (32) reveals its muscular structure. The pharynx (33) leads to the esophagus and the larynx at the upper end of the trachea. At the top of the larynx (34) are the vocal folds and epiglottis. The lungs (20) are sectioned. The pericardium (21) has been lifted off the heart and you are seeing its inner surface. The superior vena cava (35) has been cut above the heart. The back view of the liver (22) shows the cut ends of the hepatic veins above and the end of the portal vein entering the liver from below. The gall bladder (23) and bile ducts are clearly shown. The stomach (24), a portion of the transverse colon (25), and the small intestine (26) with its blood supply and anchoring root of the mesentery (36) are viewed from the back. The muscles shown are portions of the deltoid (27) of the shoulder and the sartorius (28) and a side muscle of the thigh. These are removed to expose deeper views on Plate 6.

Plate 4. This view shows the brain. You are seeing the outer surface of the right hemisphere of the cerebrum (37) and the cerebellum (38). The pons, medulla, spinal

(Continued on page following Anatomical Transparencies)

THE HUMAN BODY

IN ANATOMICAL TRANSPARENCIES

By GLADYS McHUGH, Medical Artist
Associated with the University of Chicago Clinics

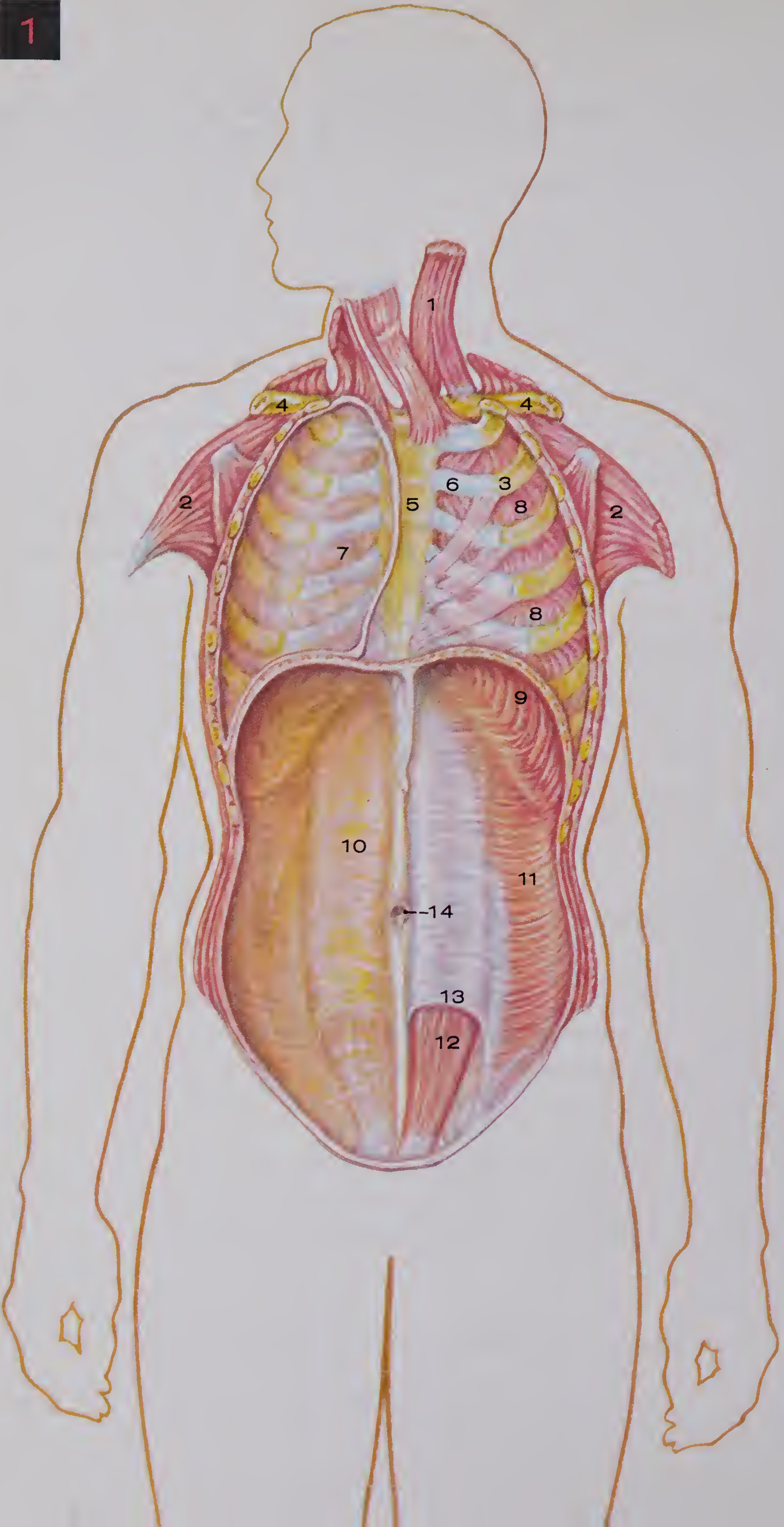
The "Trans-Vision" process presents the human body in a unique manner in which you can perform a "dissection" and proceed through the depths of its structures by turning transparent pages. You can see organs overlying other organs in a three-dimensional effect. As you turn the pages, a layer of anatomy is removed and a deeper layer comes into full view. The right pages give you a front view of the structures. To see the same structures from the back side, you turn the page. Thus, you can see the relation of organs to the body as a whole and to each other. You can single out an individual part for more detailed observation.

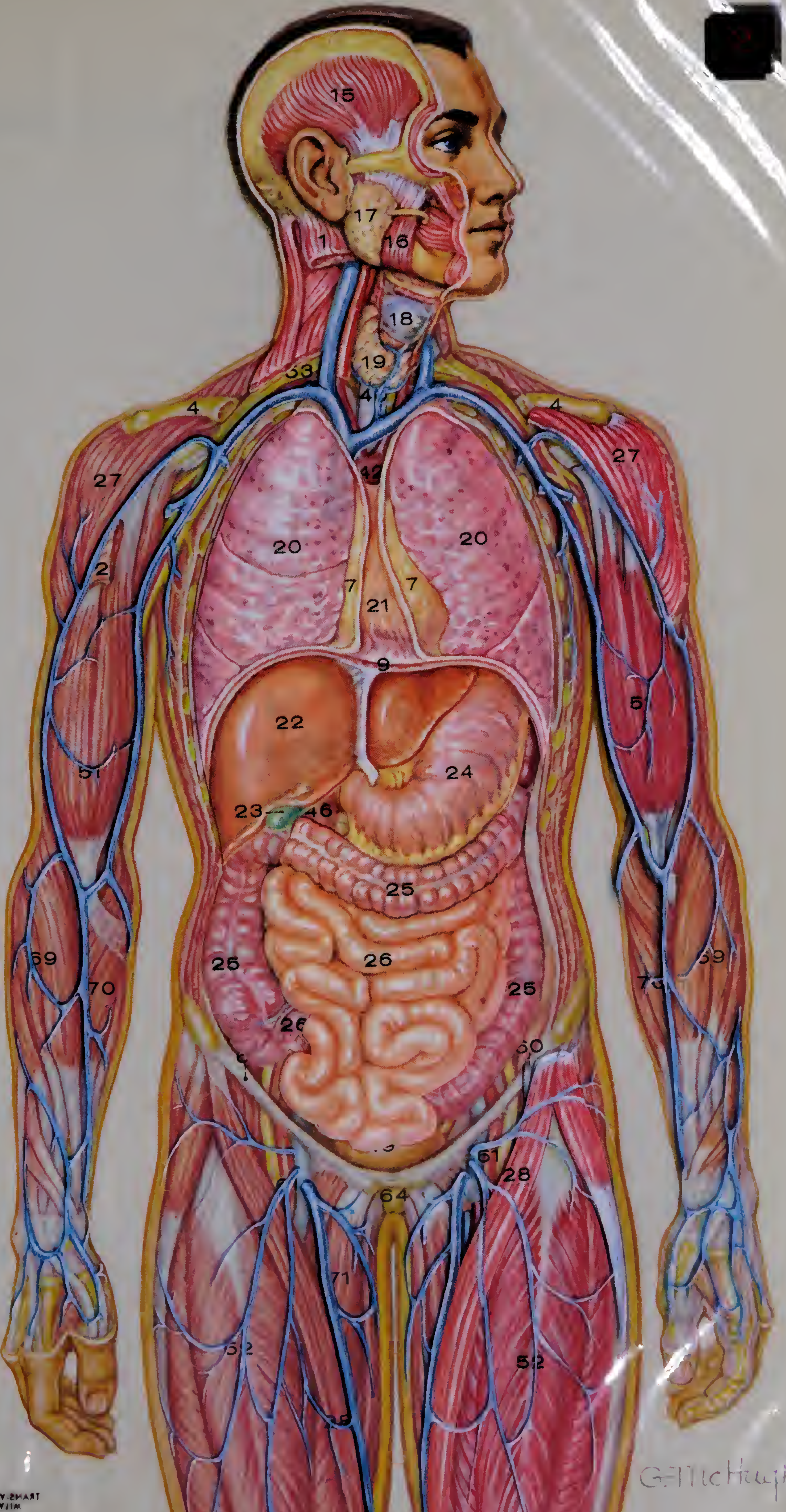
The pages preceding and following the anatomical transparencies give you a description of each view—how it was made and what it shows. The numbers you find on many of the structures refer to an identification key on the back of Plate 6. This will identify any structure you wish quickly and easily. Numbers have been omitted where they would detract from structural detail. Many such structures are referred to in the description of the various plates.

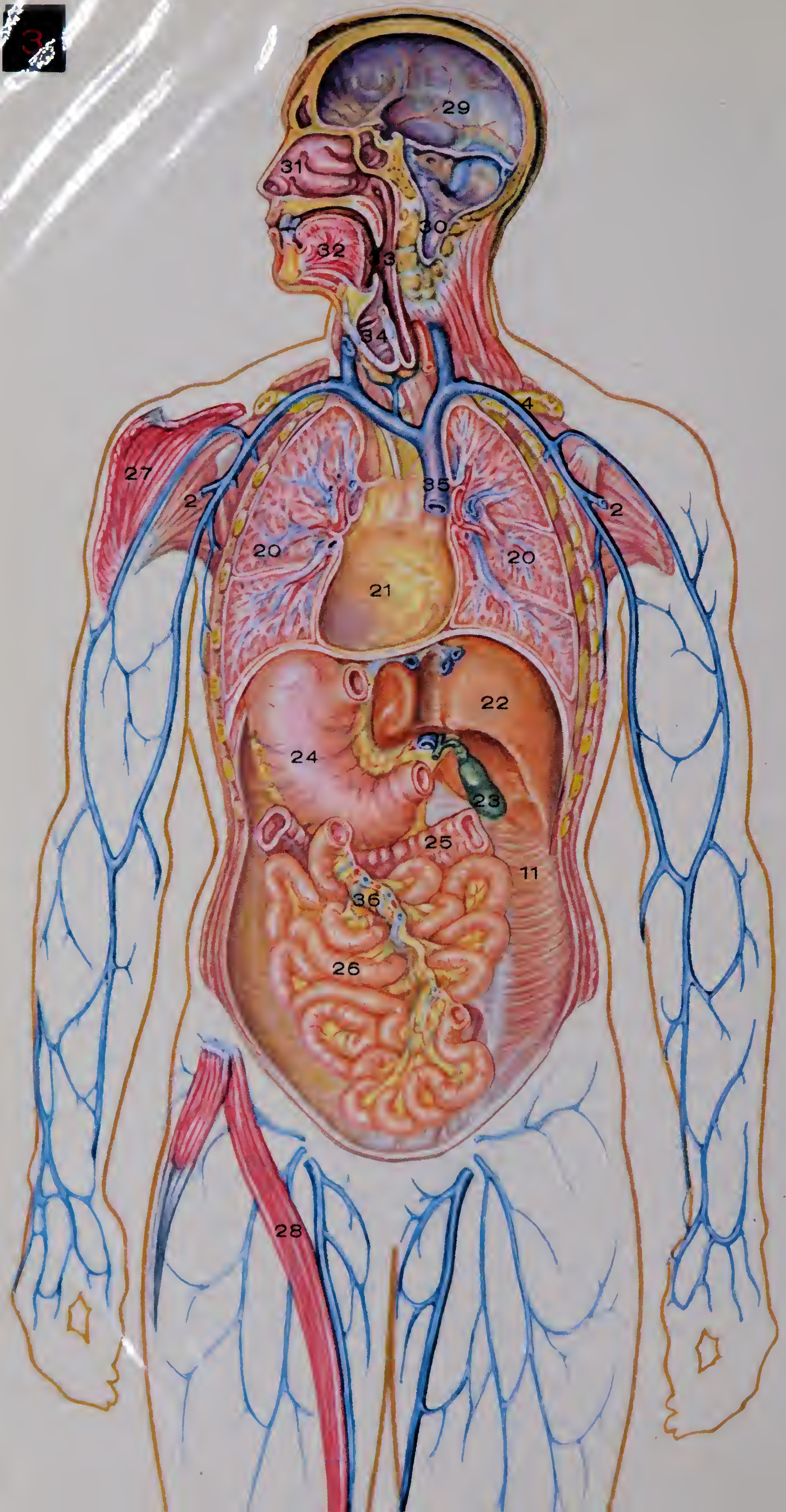
The structures shown are detailed and accurate. This presentation of the human body will serve as an adequate basis for anatomical study in any degree of thoroughness and complexity you may desire.

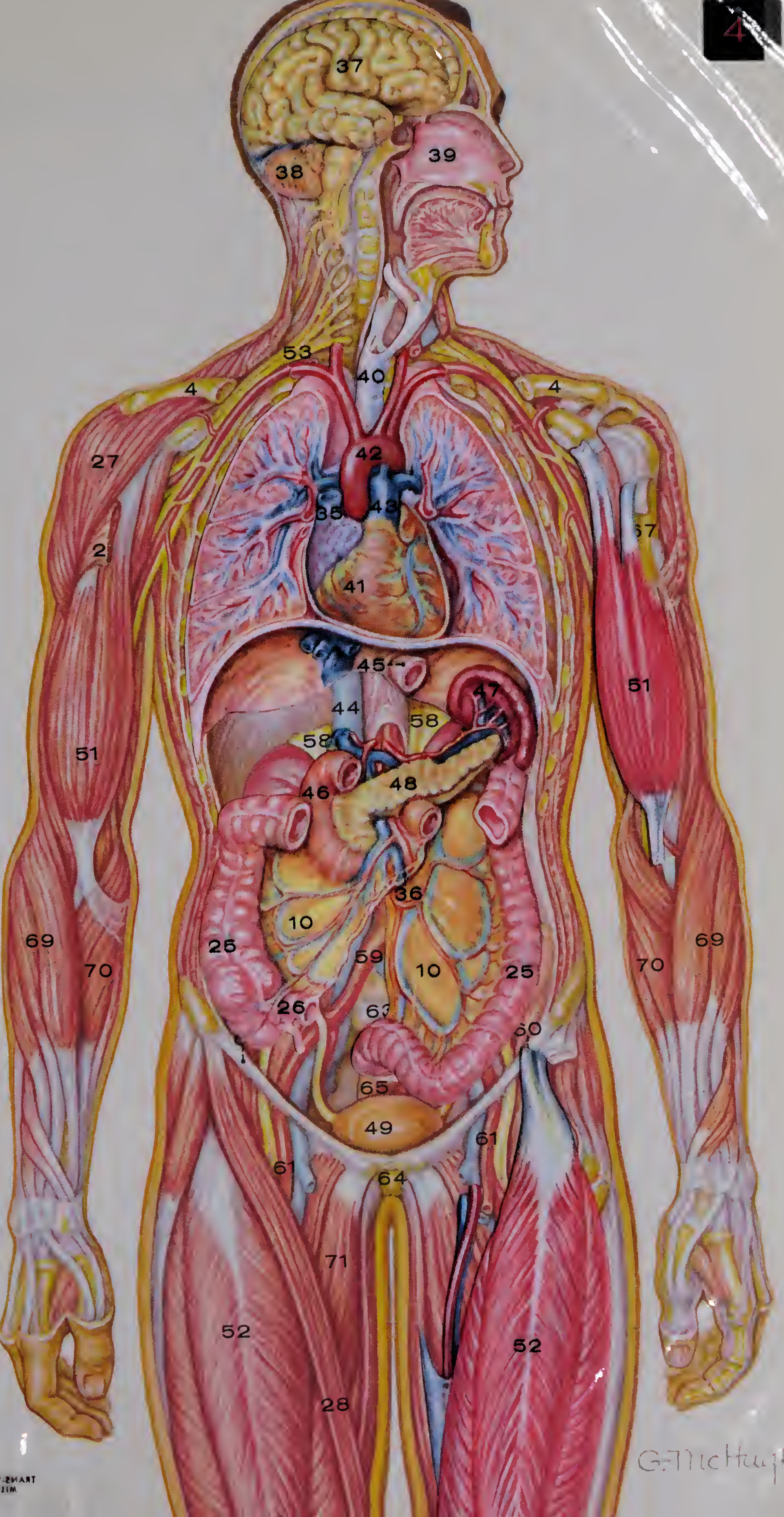
Key identifying numbered structures on back of Plate 6.

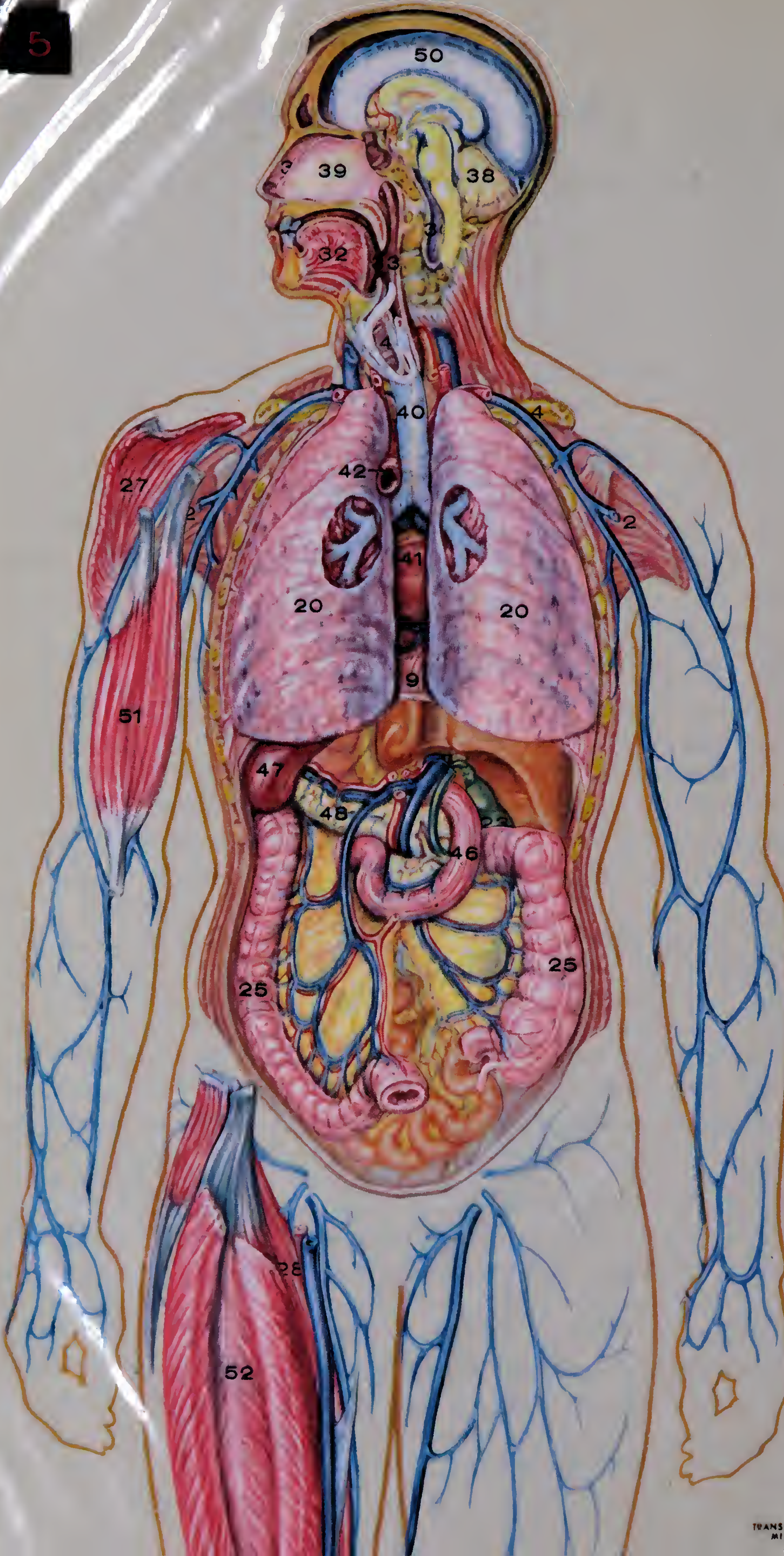
1


1
4
4
6
3
5
2
8
2
7
8
9
10
11
14
13
12


15
17
1
16
18
19
63
4
4
4
42
27
27
20
20
2
7
7
21
9
22
24
51
51
23
46
25
25
25
26
26
69
69
70
70
60
61
28
64
71
52
52
28
G. McHugh

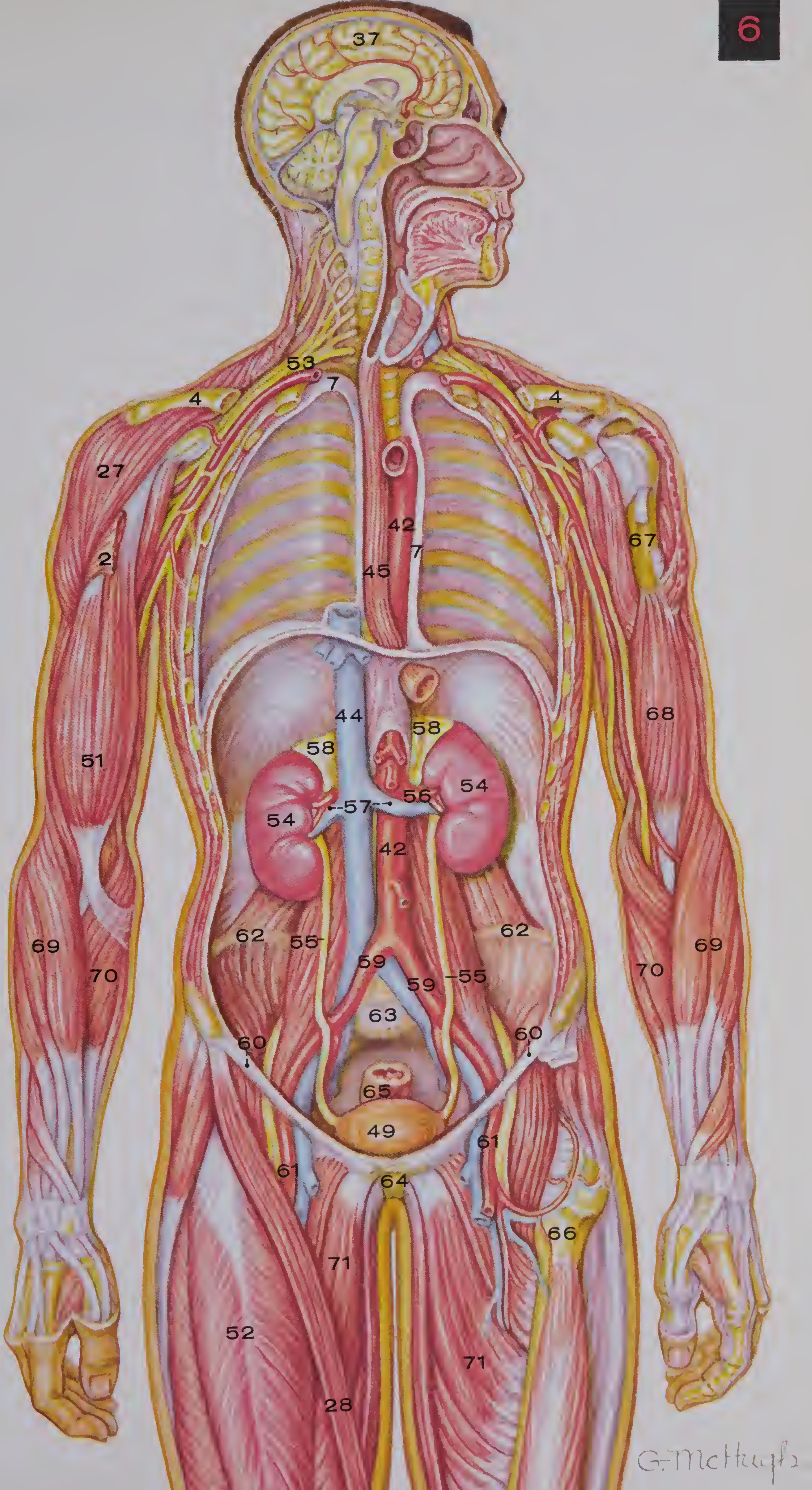

3
29
31
30
32
33
34
4
27
2
35
2
20
20
21
22
24
23
25
11
36
26
28


37
39
38
53
40
4
4
27
42
35
43
67
2
41
45
47
51
44
58
58
51
48
46
36
10
69
25
59
10
25
70
69
70
26
63
60
65
49
61
61
64
71
52
52
28
G. McHugh


50
39
38
32
3
3
3
4
40
4
42
27
2
2
41
20
20
9
51
47
48
46
25
25
28
52

TRANS VISION® MILPRINT, INC
MILWAUKEE, WISCONSIN

6


37
53
7
4
4
27
42
67
2
7
45
44
58
68
58
51
54
56
57
54
42
62
62
69
55
69
59
70
59
55
70
63
60
60
65
49
61
61
64
66
71
52
71
28
G. McHugh

Key to the Structures of the Human Body

1. Sterno-mastoid muscle, used in turning the head
2. Pectoral muscle, used in moving the arm across the chest
3. Rib
4. Clavicle
5. Sternum
6. Rib cartilage
7. Pleural membrane
8. Intercostal muscles, used in breathing
9. Diaphragm
10. Peritoneum
11. Transverse abdominal muscle, supporting the abdominal wall
12. Rectus abdominal muscle, used in flexing the trunk
13. Rectus sheath
14. Umbilicus
15. Temporal muscle, used in chewing
16. Masseter muscle, used in chewing
17. Parotid salivary gland
18. Thyroid cartilage
19. Thyroid gland
20. Lung
21. Pericardium
22. Liver
23. Gall bladder
24. Stomach
25. Colon
26. Small intestine
27. Deltoid muscle, used in raising the arm
28. Sartorius muscle, used in crossing the leg
29. Cranial cavity
30. Spinal canal
31. Nasal cavity
32. Tongue
33. Pharynx
34. Larynx
35. Superior vena cava
36. Root of the mesentery
37. Cerebrum
38. Cerebellum
39. Nasal septum
40. Trachea
41. Heart
42. Aorta
43. Pulmonary artery
44. Inferior vena cava
45. Esophagus
46. Duodenum
47. Spleen
48. Pancreas
49. Urinary bladder
50. Cerebral septum
51. Biceps muscle, used in flexing the arm
52. Flexor muscles of front of thigh
53. Brachial plexus
54. Kidney
55. Ureter
56. Renal artery
57. Renal vein
58. Adrenal gland
59. Iliac artery
60. Inguinal ligament
61. Femoral artery
62. Crest of hip bones
63. Lumbo-sacral joint
64. Pubis
65. Rectum
66. Femur
67. Humerus
68. Brachial muscle, which works with biceps as a flexor of the arm
69. Extensor muscles of hand
70. Flexor muscles of hand
71. Adductor muscles which bring legs together

cord, and spinal nerves are visible. The nasal septum (39) is the central partition of the nasal cavity. The trachea (40) is an airway to the lungs, where it divides into the bronchi. The sectioned lungs reveal the numerous branches of the bronchial tree (white), the pulmonary arteries (blue), and the pulmonary veins (red). You are looking at the heart (41) and its great vessels: the aorta (42), pulmonary artery (43), superior vena cava (35), and inferior vena cava (44). The cut ends of the hepatic veins are seen entering the inferior vena cava just below the diaphragm. In removing the stomach, the lower end of the esophagus (45) and the beginning of the duodenum (46) were cut. The spleen (47) and pancreas (48), along the back wall of the abdominal cavity, are visible. After removal of the transverse colon and the small intestine, the peritoneum (10), lining the back of the abdominal cavity and carrying blood vessels to the colon, can be seen. The lower end of the small intestine (26) is sectioned close to its junction with the colon. Just below this junction is the appendix, which extends from the caecum, or beginning portion of the colon (25). The lower end or sigmoid portion passes behind the urinary bladder (49).

Plate 5. In this view, the hemispheres of the cerebrum are divided along the midline. You are seeing the cerebral septum (50), which divides the hemispheres. Below the cerebrum you see the sectioned interbrain, pons, medulla, cerebellum (38), and spinal cord. You are viewing the lungs (20) from the back with sections removed to show the bronchial divisions of the trachea (40). With the posterior peritoneum removed, the spleen (47), pancreas (48), and duodenum (46) are visible from the back. The portal vein, which receives blood from these organs and the intestinal tract, is seen entering the liver close to the bile duct. A portion of the pancreas has been dissected to show the pancreatic duct, which enters the duodenum beside the common bile duct. The biceps muscle (51) and three thigh muscles (52) are removed and seen from the back.

Plate 6. In this view, the cerebral septum is removed and you are seeing the inner side of the left hemisphere of the cerebrum (37) with its surface blood supply. Notice the spinal nerves emerging from between the vertebrae of the neck and forming the brachial plexus (53), the nerve supply to the shoulders and arms . The arteries supplying these regions follow the same course as the nerves. With the lungs and trachea removed, you can see the full length of the esophagus (45) and its relation to the aorta (42). The inferior vena cava (44) is cut at the entrance to the heart, just above the junction with the hepatic veins. The kidneys (54), ureters (55), and bladder (49) form the urinary tract. A renal artery (56) enters each kidney from the aorta (42). The renal veins (57) drain into the inferior vena cava (44). On top of the kidneys are the adrenal glands (58). In the lower abdominal region, the aorta divides into the iliac arteries (59), which divide further into internal and external branches. The internal iliac arteries supply the pelvic organs. The external iliacs encircle the pelvic region, pass under the inguinal ligaments (60) in company with the femoral veins and nerves, and emerge as the femoral arteries (61). Portions of the bone structure of the pelvis are visible as the crests of the hip bones (62), the joint between the sacrum and spine (63), and the pubis (64). The upper end of the rectum (65) can be seen behind the bladder. The shoulder and hip joints are partially exposed on the left side, showing bone and muscle structures not visible on the right side. Additional muscles and bones of the arms and legs are identified in the Key to the Structures of the Human Body.

BLOOD AS A TRANSPORTING MEDIUM

Transportation of	*From*	*To*	*For the Purpose of*
Digested food	Digestive organs and liver	Tissues	Growth and repair of cells, supplying energy, and regulating life processes
Cell wastes	Active tissues	Lungs, kidneys, and skin	Excretion
Water	Digestive organs	Kidneys, skin, and lungs	Excretion and equalization of body fluids
Oxygen	Lungs	Tissues	Oxidation
Heat	Tissues	Skin	Equalization of the body temperature
Secretions	Ductless glands	Various organs, glands	Regulation of body activities

The thrombin changes *fibrinogen*, a blood protein, to *fibrin*. The fibrin is a network of tiny threads that trap blood cells, thus forming a clot, and prevent further escape of blood (Fig. 42–2). These trapped corpuscles dry out and form a scab. Healing takes place as the edges of the wound grow toward the center. If any of the substances mentioned above is not present, clotting will not occur. Clotting is summarized in the table below.

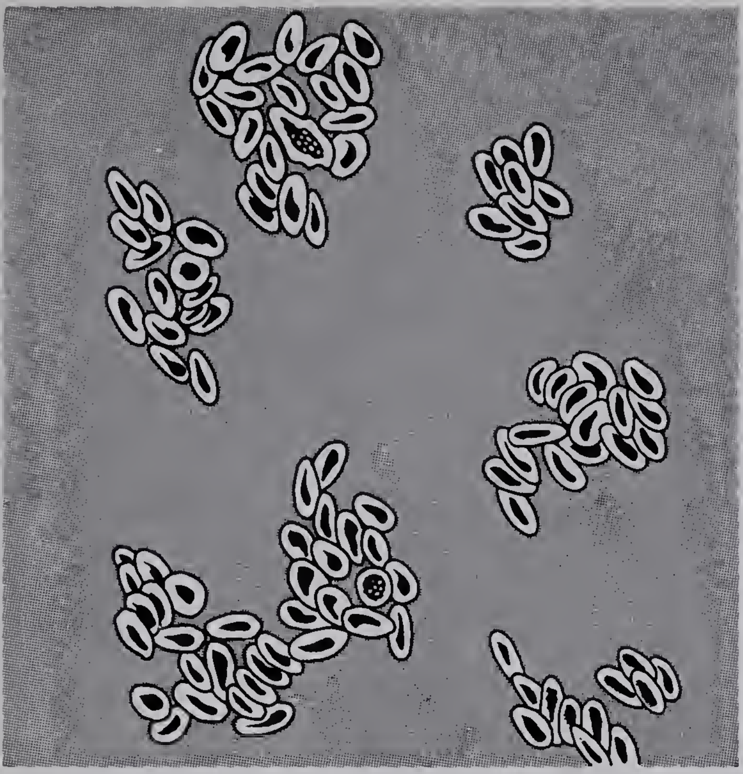
If blood vessels are broken under the skin in a bruise, a black-and-blue spot may appear, because clotting occurs under the skin. Gradually the clotted blood is absorbed and the color of the bruise changes and finally disappears.

THE CLOTTING OF BLOOD

Thromboplastin + prothrombin + calcium = thrombin
Thrombin + fibrinogen = fibrin

Blood transfusions have saved many lives. Conditions like hemorrhage, wound shock, severe burns, and various other illnesses may require blood transfusions. If whole blood is used, the patient receives both the necessary plasma and blood cells. However, the blood of the donor must be typed and matched with that of the patient. The matching is done by adding a drop of a test serum to a drop of the donor's blood. If the red cells ***agglutinate***, or clump together, the bloods are incompatible (Fig. 42–3). If, however, the red cells remain in suspension, the samples are compatible, and it is possible to perform the transfusion. Blood types are designated A, B, AB, and O. You can see why using the wrong type might result in serious blood reactions, clotting, and death of the patient.

Often the patient needs an immediate increase in the volume of liquid in the blood stream and does not require additional blood cells. This con-



42-3 This diagram of a blood smear shows the agglutination reaction that occurs when incompatible types of blood are mixed. When two compatible types are mixed there is no such reaction.

dition is called *shock*. The red corpuscles form rapidly if the blood volume is maintained. At such times plasma may be transferred in preference to whole blood. Typing is not necessary when plasma is used for transfusion because of the absence of the cells.

The Rh factor in blood. A factor in blood independent of the A, B, AB, and O blood groups is called the ***Rh factor,*** after the *Rhesus* (*ree*-sus) monkey in which it was discovered. About 85 percent of the people in the United States have this factor in their blood and are designated as *Rh positive*. The other 15 percent are *Rh negative*. The Rh factor, like the other blood types, is inherited, and is actually any one of six protein substances called *antigens*.

If a patient is Rh negative and receives Rh-positive blood in a transfusion, he produces an antibody against the factor. This particular antibody causes the corpuscles of the Rh-positive blood to agglutinate and to dissolve. There is little danger during the first transfusion because the antibody is not present when the Rh-positive blood is added. But the patient now builds antibodies against this Rh-positive blood, so that a second transfusion may result in serious or even fatal complications.

How the Rh factor may affect childbirth. Complications from the Rh factor occur with childbearing in about one in three or four hundred mothers. When the mother is Rh negative and the father is Rh positive, the child may inherit the Rh-positive factor from the father. During development, blood from the child, containing the factor, may seep into the mother's circulation through tiny ruptures in the membranes that normally separate the two circulations. Blood from the mother seeps into the child through the same channels.

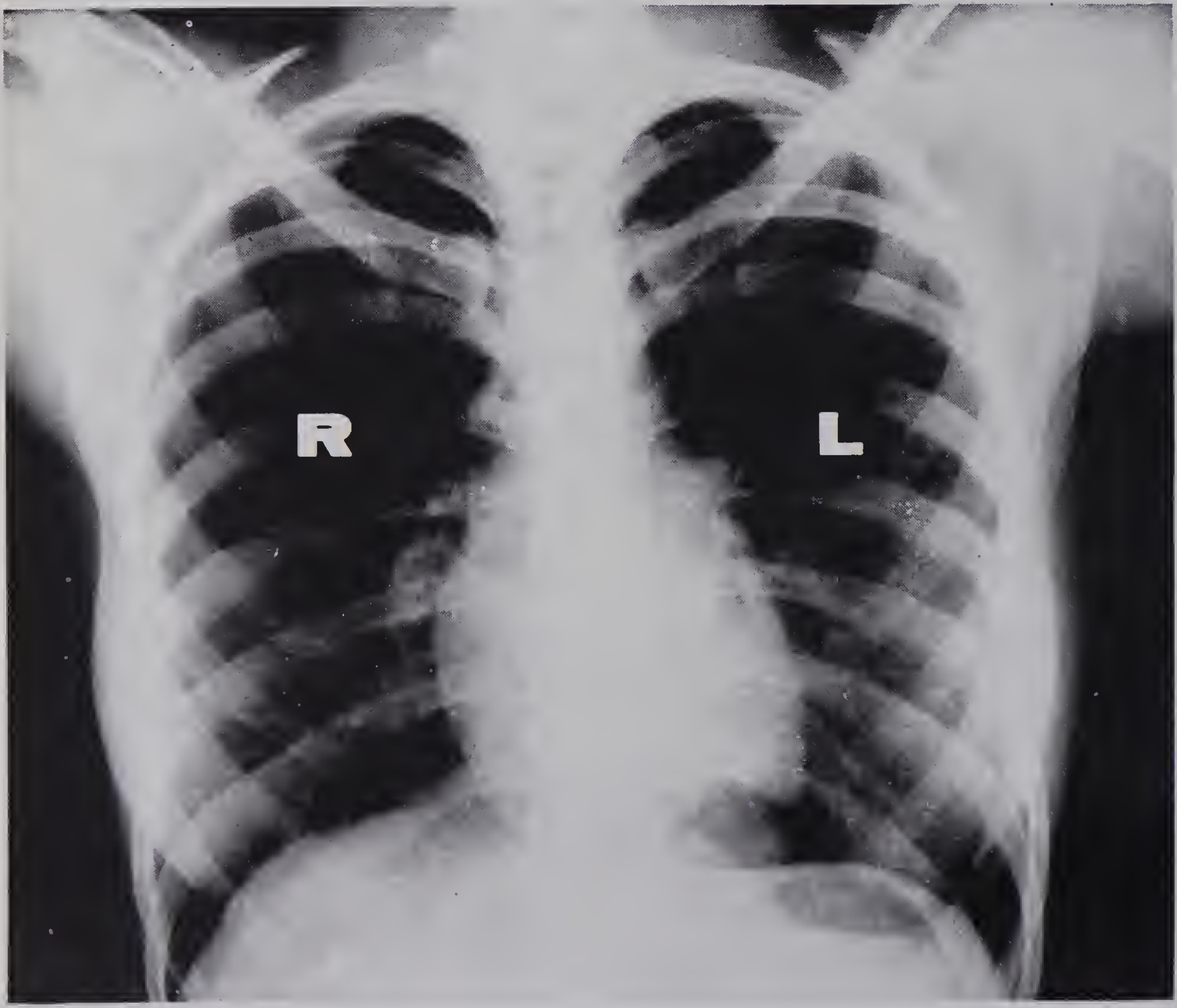
Since such seepage is uncommon, many Rh-negative mothers bear normal Rh-positive children. However, if seepage occurs again with a second Rh-positive child, the antibody in the mother's blood, produced in the first pregnancy, enters the child's circulation and causes serious damage. Occasionally the child dies before birth. But if the damage to the child is not too extensive, an immediate transfusion after birth may save its life. Sometimes the child's blood is almost entirely removed and replaced by transfused blood. Blood used in such a complete transfusion is Rh negative but does not contain the antibody. In other words the donor has never received positive blood and his blood is not sensitized against the factor.

The structure of the heart. The heart is a cone-shaped muscular organ situated under the breastbone and between the lungs (Fig. 42–4). It is enclosed in a sac called the ***pericardium*** (pair-i-*kahrd*-

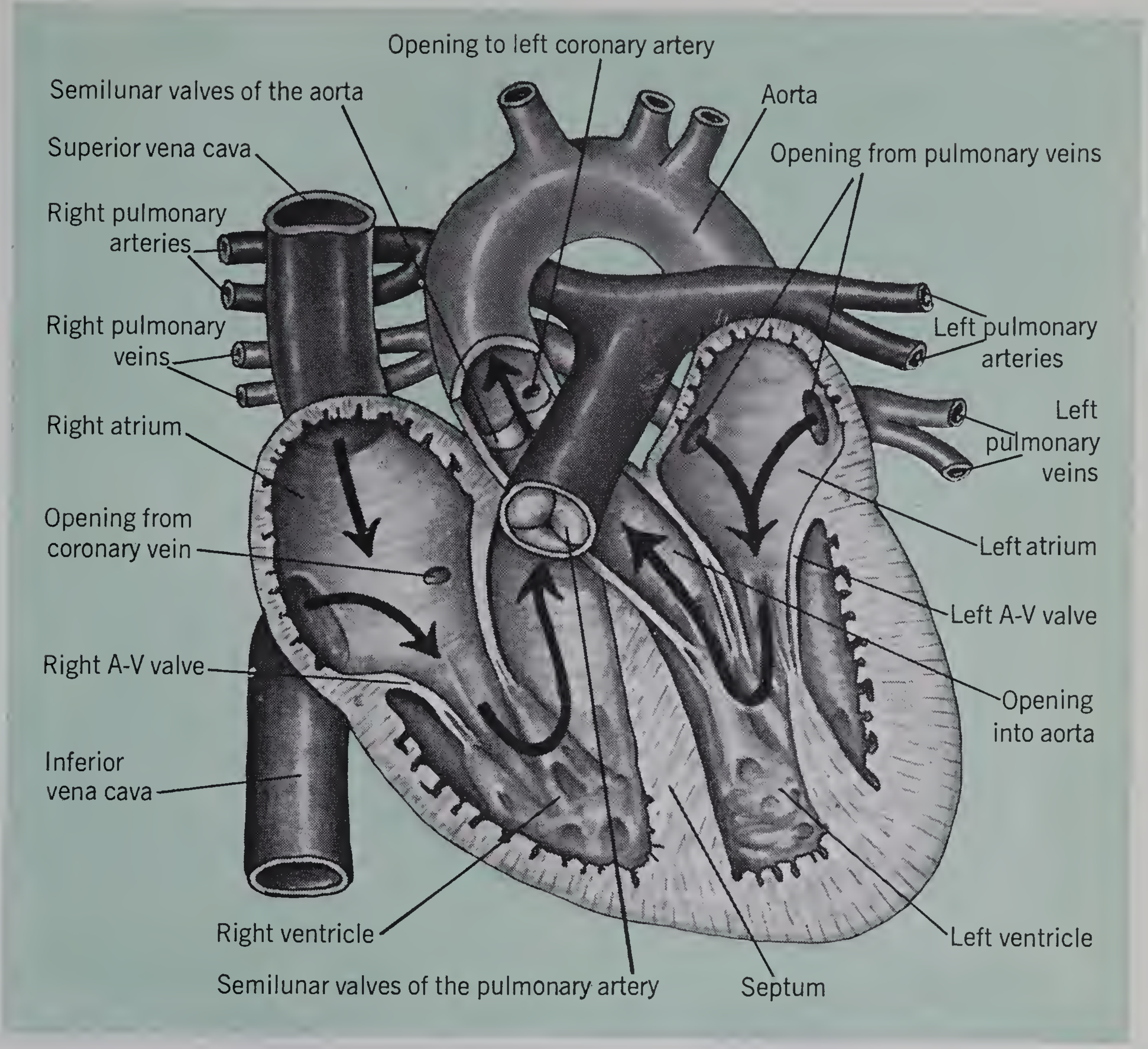
ee-um). It usually lies a little to the left of the midline of the chest cavity, with its point extending downward and to the left between the fifth and sixth ribs. Since the beat is strongest near the tip, many people have the mistaken idea that the entire heart is on the left side.

The heart is composed of two sides, right and left. The two halves are entirely separated by a wall called the ***septum.*** Each half is composed of two chambers, a relatively thin-walled ***atrium,*** and a thick, muscular ***ventricle.*** The two atria act as reservoirs for the blood entering the heart. Both contract at the same time, filling the two ventricles rapidly. Next the thick muscular walls of the ventricles contract, forcing the blood out through the great arteries.

Flow of blood from the ventricles under pressure and maintenance of pressure in the arteries between beats require two sets of one-way heart valves. The valves between the atria and ventricles, called the *atrioventricular valves*, or ***a-v valves,*** are flaplike structures which are anchored to the floor of the ventricles by tendonlike strands (Fig. 42–5). Blood passes through these valves freely into the ventricles. The valves cannot be opened from the lower side, however, because of the tendons anchoring them.



42-4 This X-ray photograph shows a normal heart and lungs as seen from the front. Notice that the heart points toward the patient's left side. The curved area below the heart is the diaphragm. (Indiana University Medical Center)


Opening to left coronary artery
Semilunar valves of the aorta
Aorta
Superior vena cava
Opening from pulmonary veins
Right pulmonary arteries
Right pulmonary veins
Left pulmonary arteries
Right atrium
Left pulmonary veins
Opening from coronary vein
Left atrium
Left A-V valve
Right A-V valve
Opening into aorta
Inferior vena cava
Right ventricle
Left ventricle
Semilunar valves of the pulmonary artery
Septum

42-5 Notice the location of the valves in relation to the heart chambers and blood vessels. The arrows indicate the direction of blood flow.

Thus blood is unable to flow backward into the atria during contraction of the ventricles. Other valves, called the *semilunar valves,* or ***s-l valves,*** are located at the openings of the arteries. These cup-like valves are opened by the force of blood passing from the ventricles into the arteries, and they prevent blood from returning to the ventricles.

Circulation of blood through the heart. Blood first enters the right atrium of the heart by way of the ***superior vena cava*** (*vee*-na *kahv*-a), and the ***inferior vena cava.*** The superior vena cava carries blood from the head and upper parts of the body. The inferior vena cava returns blood from the lower body regions. From the right atrium blood then passes through the right a-v valve into the right ventricle. When the right ventricle contracts, blood is forced through a set of s-l valves into the *pulmonary artery,* which carries the blood to the lungs. After the blood has passed through the lungs, it is returned to the heart through the right and left *pulmonary veins.* These vessels open into the left atrium, from which the blood passes through the left a-v valve into the left ventricle. From here blood passes out the ***aorta*** (ay-*ort*-a), and is distributed to all parts of the body.

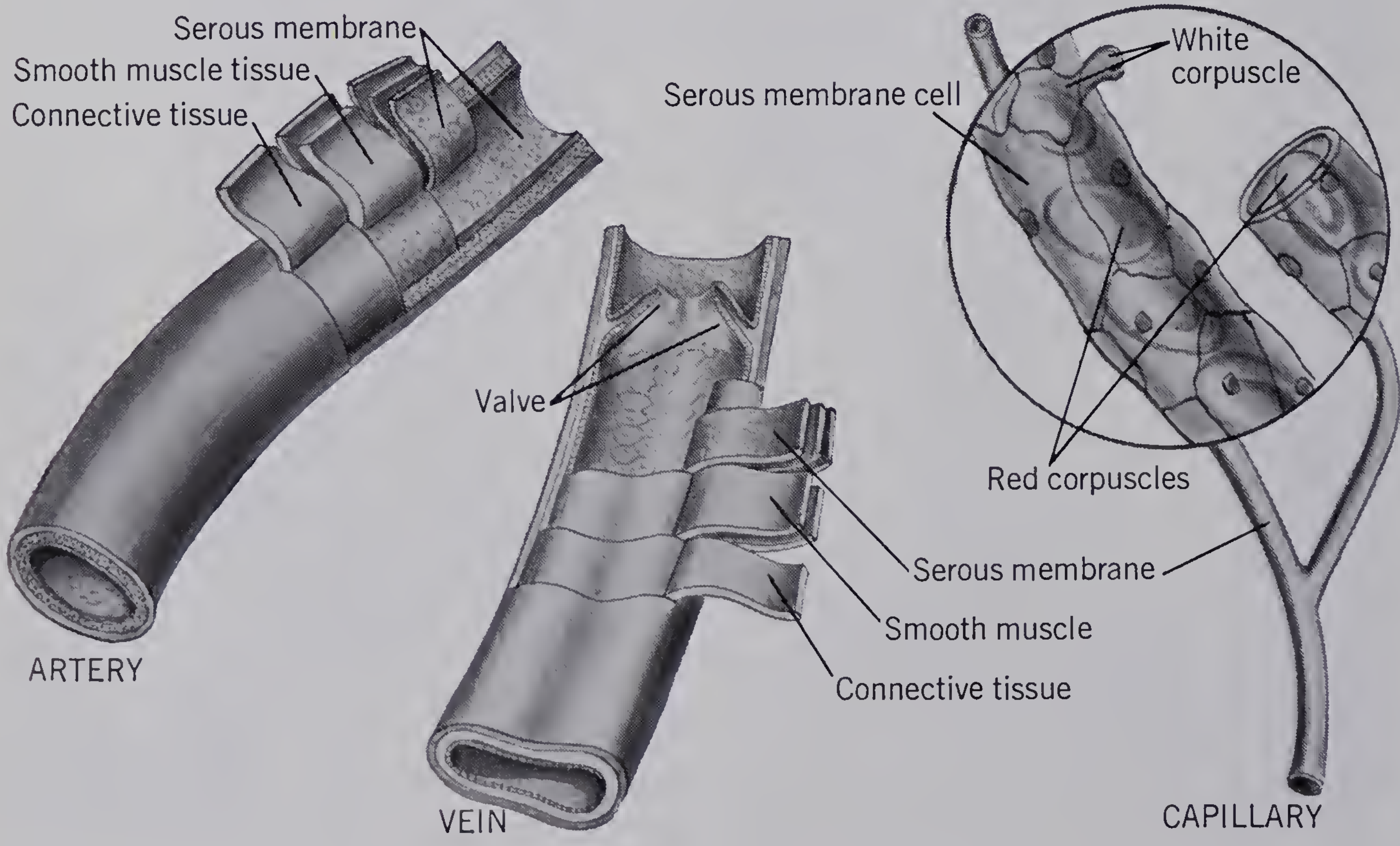
Although the heart is an organ filled with blood, its muscle layers are too thick to be nourished by this blood. The cells receive special nourishment through arteries called *coronary arteries.* There is an enlargement of the aorta at the point where it leaves the heart. This is called the ***aortic sinus.*** From here, the right and left coronary arteries branch off. These arteries curve downward around each side of the heart, sending off smaller vessels that penetrate the heart muscle.

The heart, a highly efficient pump. A complete cycle of heart activity, or beat, consists of two phases. During one part of the cycle, called ***systole,*** the ventricles contract and force blood into the arteries. During the other part, called ***diastole,*** the ventricles relax and receive blood from the atria.

The sounds you hear in a stethoscope when you listen to a normal heart sound like the syllables "lub" and "dup" repeated over and over in perfect rhythm. The "lub" is the sound of the contraction of the muscles of the ventricles and the closing of the a-v valves during systole. The "dup" is the closing of the semilunar valves at the base of the arteries during diastole.

At rest the heart of an average man beats about 70 times per minute. During strenuous work or exercise the heart rate may be as high as 180 beats per minute.

With the body at rest the heart pumps about 10½ pints of blood per minute. Your body contains 12 pints of blood, so that all the blood makes a complete circulation through the body in slightly over a minute. However, mild exercise such as walking speeds the heart output to about 20 pints per minute, and strenuous exercise may increase it to as much as 42 pints per



42-6 Notice the difference in structure in these three types of blood vessels. In the drawing of the capillary, the white corpuscle is squeezing through the wall between cells and will then pass into the tissue spaces.

minute. If you were to use a hand pump to move blood, you could not possibly keep up with a heart under exertion. This will give you some idea of the efficiency of this organ which weighs only a quarter of a pound and works every minute of every day and night of your life.

The blood vessels. Blood moves in a system of tubes of varying sizes (Fig. 42–6), which have been classified as follows: ***arteries*** and ***arterioles,*** vessels carrying blood *away* from the heart; ***capillaries,*** very small, thin-walled vessels; and ***veins*** and ***venules,*** vessels carrying blood back *toward* the heart.

The aorta branches into several large arteries. These arteries branch and become arterioles. As the arterioles branch, they soon become capillaries, which are the smallest vessels in the body. After passing through a tissue or organ, the capillaries come together to form venules. As the venules join, they become veins, which take the blood toward the inferior or superior vena cava and into the right atrium of the heart.

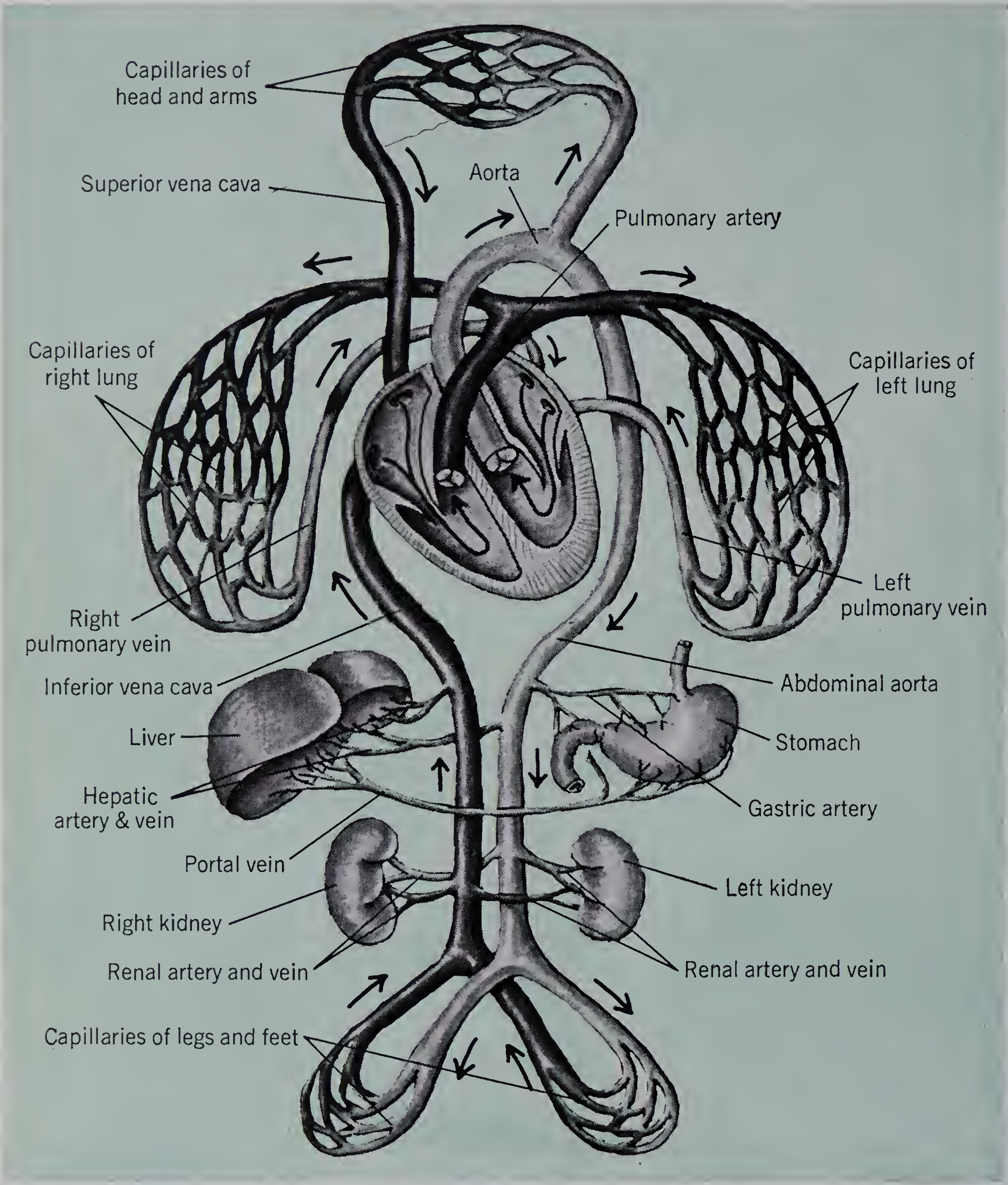
Arteries have elastic, muscular walls and smooth linings. Because of their elasticity, arteries can expand and absorb part of the great pressure resulting from contraction of the ventricles at systole. The pressure in the aorta leading from the left ventricle is greater than that in the pulmonary artery pumped by the smaller right ventricle. If the aorta were cut, blood would spurt out in a stream of six feet or more. When the ventricles contract, arterial pressure is greatest and is called *systolic pressure.* The elasticity of the artery walls maintains part of this pressure while the ventricles are at rest. This is the time of lowest pressure in the arteries, or *diastolic pressure.* The bulge in an artery wall caused by systolic pressure can be felt in the wrist or any part of the body where an artery is near the surface. This ***pulse*** has the same rhythm as do the heart beats.

What are capillaries? As arterioles penetrate the tissues, they branch into capillaries (Fig. 42–6). Capillaries differ from arterioles in that their walls are only one cell layer thick. Capillaries are only slightly greater in diameter than the red blood cells. Red corpuscles must pass through them in single file and may even be pressed out of shape by the capillary walls.

Dissolved foods, waste products, and gases pass freely through the thin walls of capillaries and in and out of the tissue spaces. Tiny openings in the walls are penetrated by white corpuscles as they leave the blood stream and enter the tissue spaces. Also in the capillaries, part of the plasma diffuses from the blood and becomes tissue fluid. Thus, all the vital relationships between the blood and the tissues occur in the capillaries and not in arteries and veins.

Vein structure and function. On leaving an organ, capillaries unite to form veins. Veins carry dark-red blood; that is, blood containing less oxygen. In the skin the veins have a bluish color because the skin contains a yellow pigment that changes the appearance of the dark-red blood. The walls of veins are thinner and less muscular than those of arteries, and their internal diameter is proportionally larger. Many of the larger ones are provided with cuplike valves that prevent the backward flow of blood.

Veins have no pulse wave, and the blood pressure within them is much lower than that of arteries. Blood pressure resulting from heart action is almost completely lost as blood passes through the capillaries. Blood from


Capillaries of head and arms
Superior vena cava
Aorta
Pulmonary artery
Capillaries of right lung
Capillaries of left lung
Left pulmonary vein
Right pulmonary vein
Inferior vena cava
Abdominal aorta
Liver
Stomach
Hepatic artery & vein
Gastric artery
Portal vein
Left kidney
Right kidney
Renal artery and vein
Renal artery and vein
Capillaries of legs and feet

42-7 This drawing is a diagrammatic representation of the various circulations in the human body. Identify pulmonary, systemic, coronary, renal, and portal circulations.

the head may return to the heart with the aid of gravity, but in the body regions below the level of the heart other factors are required. Venous flow from these regions is aided by the working muscles and by the vacuum created in the chest during inspiration.

Circulations in the body. A four-chambered heart, such as that in the human body, is really a double pump in which the two sides work in unison. Each side pumps blood through a major division of the circulatory system. The right side of the heart receives dark, deoxygenated blood from the body and pumps it through the arteries of the ***pulmonary circulation.*** The great pulmonary artery, extending from the right ventricle, sends a branch to each lung (see the "Trans-Vision" between pages 584 and 585). These arteries in turn branch within the lungs, forming a vast number of arterioles. Here the blood discharges carbon dioxide and water and receives oxygen. Oxygenated blood, now bright scarlet in color, leaves the lungs and returns to the left atrium of the heart through the pulmonary veins.

Oxygenated blood passes through the left chambers of the heart and out the aorta under great pressure. The blood is now in the ***systemic circulation,*** which supplies the body tissues. This extensive circulation includes all of the arteries that branch from the aorta, the capillaries that penetrate the body tissues, and the vast number of veins that lead to the venae cavae. The systemic circulation also includes several shorter circulations that supply or drain special organs of the body.

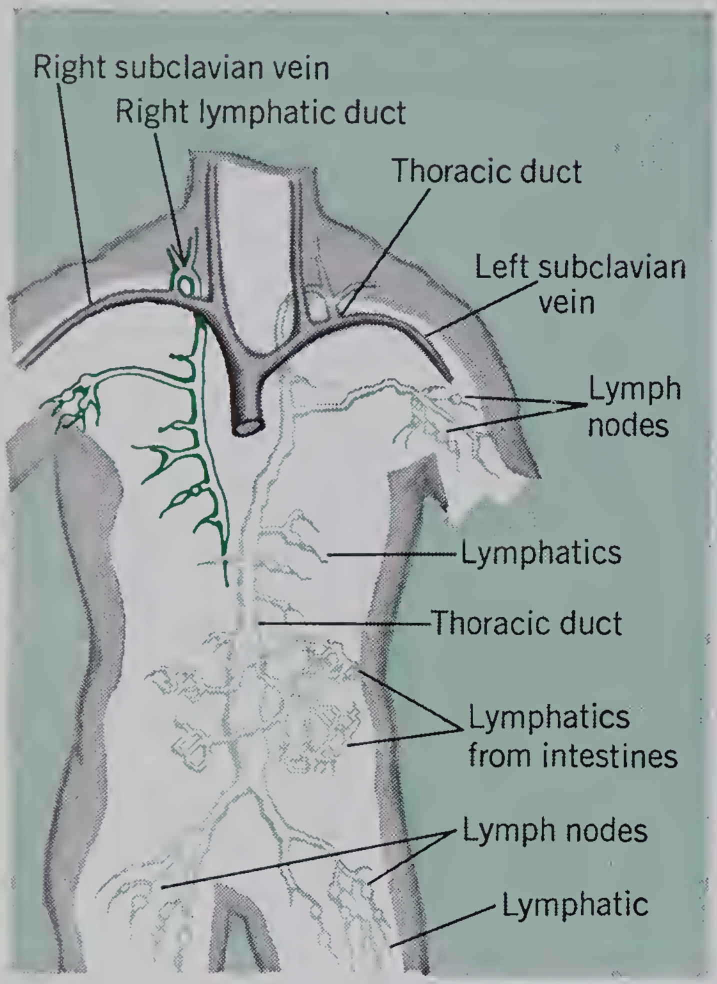
The ***coronary circulation,*** referred to in the discussion of the heart muscle, supplies the heart itself. This short but vital circulation begins at the aorta and ends where the coronary veins empty into the right atrium. Every beat of the heart depends on the free flow of blood through the coronary vessels.

The ***renal circulation*** starts where a *renal artery* branches to each kidney from the aorta. It includes the capillaries that penetrate the kidney tissue and the *renal veins,* which return blood from the kidneys to the inferior vena cava. Blood on this route nourishes the kidneys and discharges water, salts, and nitrogenous cell wastes. Thus, even though it is low in oxygen content, blood in the renal veins is the purest.

The ***portal circulation*** includes an extensive system of veins that lead from the spleen, stomach, pancreas, small intestine, and colon. The large veins of the portal circulation unite to form the portal vein, which enters the liver. Blood flowing from the digestive organs transports digested food and water. Blood laden with food for the body tissues flows from the liver in the hepatic veins, which in turn empty into the inferior vena cava, thus ending this vital branch of the systemic circulation.

Return of tissue fluid to the circulation. The tissue fluid that bathes the cells is collected in tubes and is then called ***lymph*** (limf). These tiny lymph vessels join one another and become larger lymph vessels in the same way that capillaries join to form venules. Lymph nodes, which are enlargements in the lymph vessels, are located along the vessels much like beads on a string. In these lymph nodes, the lymph tubes break up into many fine vessels once again. Here certain white corpuscles collect and destroy bacteria that may be in the lymph. The lymph glands, then, act to strain, or to purify, the lymph before returning it to the blood. The greatest concentrations of these lymph nodes are in the neck, the armpit, the bend of the arm, and the groin. Often when there is an infection in the hand or arm, the lymph nodes of the armpit swell and become painful. Both the *tonsils* and *adenoids* in the throat are merely masses of lymphatic tissue that often become inflamed during childhood and have to be surgically removed.

The lymph of the right side of the head, neck, and right arm enters into a larger vessel named the *right lymphatic duct.* This vessel returns the lymph to the blood by opening into the *right subclavian vein.* The lymphatics from the



42-8 The lymphatics course throughout the entire body. At what point does the lymphatic system join the bloodstream?

rest of the body drain into the *thoracic duct*, which in turn empties into the *left subclavian vein* (Fig. 42–8).

In the walls of the larger lymph vessels are valves to control the flow of lymph. These valves are similar in structure to those found in the veins. In inactive tissues lymph flows very slowly or is completely stagnant. When activity increases, the fluid flows faster. The return of lymph to the blood stream is aided by the contracting movements of many of our body muscles.

Removal of wastes from the circulating fluids. The oxidation of foods involved in metabolism produces waste products that must be given off by the body in the process called ***excretion.*** In protein metabolism, waste products result from the separation of the carbon and nitrogen parts of amino acids before oxidation of the carbon part. Other waste products result from the synthesis of proteins from amino acids during growth processes. These nonprotein ***nitrogenous wastes*** include *urea* and *uric acid.*

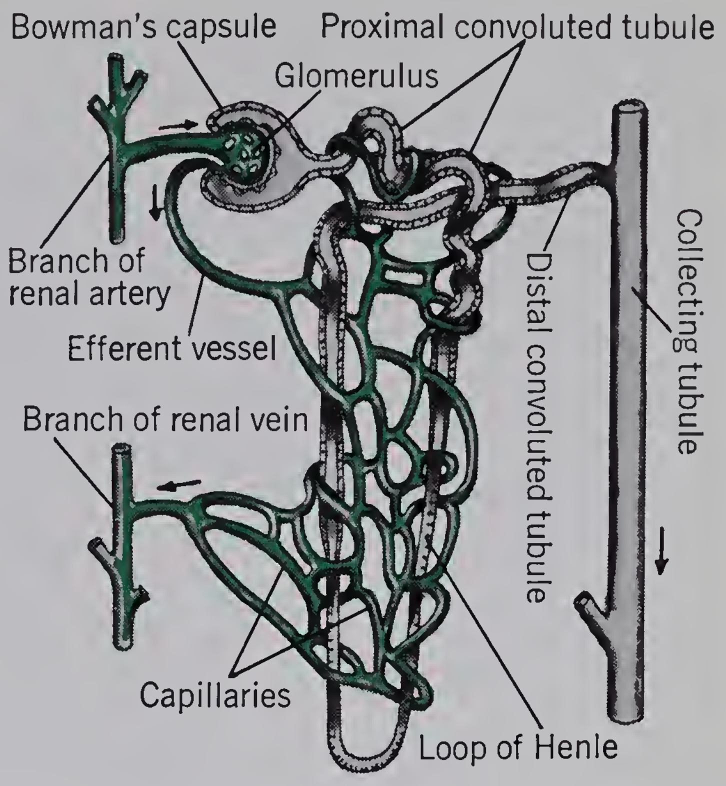
Any great accumulation of wastes in the tissues, especially nonprotein nitrogens, causes rapid tissue poisoning, starvation, and eventually suffocation. Tissues filled with waste products cannot absorb either food or oxygen. Fever, convulsions, coma, and death are inevitable if nonprotein wastes do not leave the tissues.

Further complications arise if mineral acids and salts accumulate in the body because of excretory failure. This accumulation disturbs certain delicate acid-base balances in the body and also upsets the osmotic relationships between blood and lymph and the tissues. When excess salts are held in the tissues, water accumulates and causes swelling.

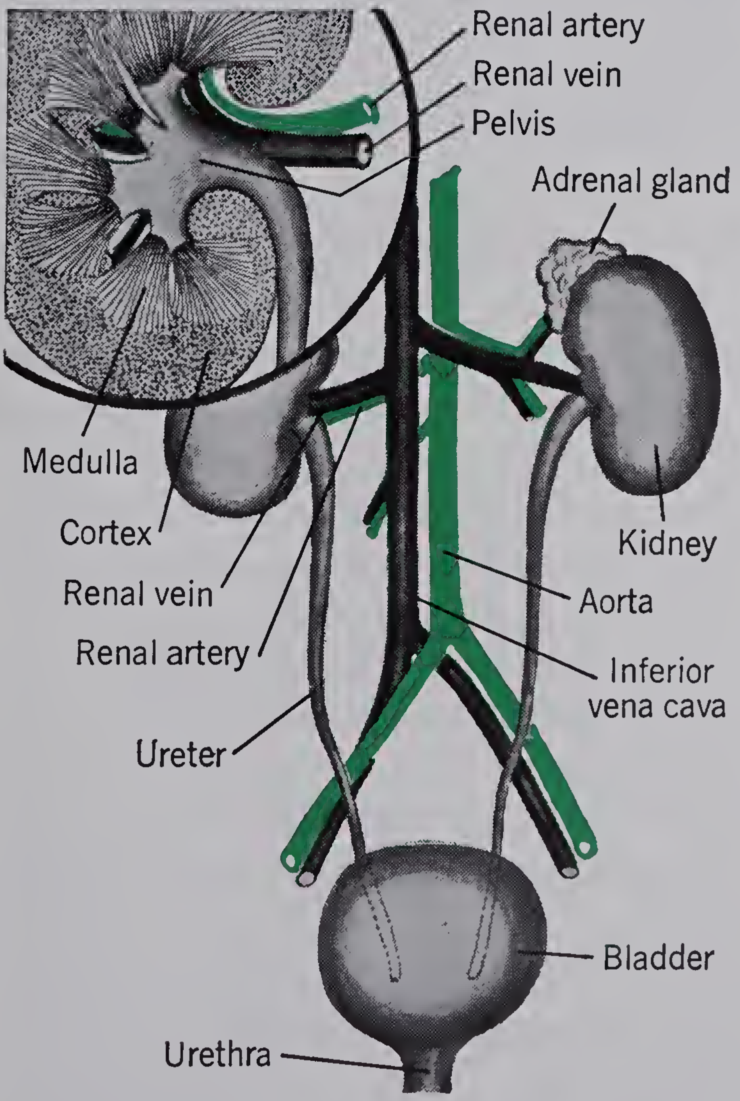
One-celled organisms and animals like the sponge and jellyfish discharge their cell wastes directly into a water environment. However, when many millions of cells form an organism, as in higher animals, the removal of cell waste products becomes a complicated process involving many organs. Each cell discharges its waste materials into the tissue fluid, which in turn reaches the blood stream. The blood transports the cell wastes to excretory organs such as the kidneys, lungs, and skin for elimination.

The kidneys – the principal excretory organs. The kidneys are bean-shaped organs, about the size of your clenched fist. They lie on either side of the spine, in the "small" of the back. Deep layers of fat around them form a protective covering (see the "Trans-Vision" between pages 584 and 585). If you cut a kidney lengthwise (Fig. 42–9), you can see several different regions. The firm, outer region which composes about one third of the kidney tissue is called the ***cortex.*** The inner two thirds, or ***medulla,*** contains conical projections called ***pyramids.*** The points of the pyramids extend into a saclike cavity, the ***pelvis*** of the kidney. The pelvis in turn leads into a long, narrow tube (one for each kidney) called the ***ureter*** (yoo-*reet*-er). The two ureters empty into the ***urinary bladder.***

Each kidney contains about 1,250,000 tiny filters called ***nephrons.*** The function of these nephrons is to control the chemical composition of blood. Each nephron consists of a small, cup-shaped structure called a ***Bowman's capsule*** (Fig. 42–10). A tiny, winding ***tubule*** comes from each capsule. This tubule becomes very narrow as it straightens out and goes toward the renal pelvis. This tubule widens out again into a loop called *Henle's loop* and goes back into the cortex. Once this tubule has passed back into the cortex, it becomes very crooked again and then enters a larger straight tube called the *collecting tubule.* The collecting tubule is a straight tube which receives the tubules of many nephrons. It carries fluid to the renal pelvis. If all these tubules were straightened out and put end to end, they would extend over 200 miles.


Bowman's capsule
Proximal convoluted tubule
Glomerulus
Branch of renal artery
Efferent vessel
Branch of renal vein
Distal convoluted tubule
Collecting tubule
Capillaries
Loop of Henle

42-10 This diagram shows the close relationship of nephron and the blood vessels by which materials are reabsorbed into the blood.


Renal artery
Renal vein
Pelvis
Adrenal gland
Medulla
Cortex
Renal vein
Renal artery
Kidney
Aorta
Inferior vena cava
Ureter
Bladder
Urethra

42-9 In the drawing at the upper left the kidney has been cut away to show its internal structures. The cortex contains millions of glomeruli.

How does the nephron function? Blood enters each kidney through a large *renal artery,* which branches directly from the aorta. It is the largest artery in the body in proportion to the size of the organ it supplies. In the kidney the renal artery branches and rebranches to form a maze of tiny arterioles, which penetrate all areas of the cortex.

Each arteriole ends in a coiled, knoblike mass of capillaries, the ***glomerulus*** (glah-*mer*-[y]e-lus). Each glomerulus fills the cuplike depression of the Bowman's capsule. In the first stage of removal of waste from the blood, far too much of the blood content leaves the blood stream and enters the Bowman's capsule. However, this is soon corrected in a second stage, in which valuable substances return to the blood. The first stage takes place in the coiled capillaries of the glomeruli. Here water, nitrogenous wastes, glucose, and mineral salts pass through the walls of the capillaries and into the surrounding capsule. This solution resembles blood plasma without blood proteins. Complete loss of this much water, glucose, and minerals would be fatal. However, after this fluid leaves the capsule through the tubules, it passes a network of capillaries. Here, many of the substances are reabsorbed into the blood. Only nitrogenous wastes, excess water, and excess mineral salts pass through the tubules to the pelvis of the kidney as ***urine.***

Some recent studies of kidney function indicate that, for every 100 cc of fluid that pass from the blood in the glomeruli into the capsules, 99 cc are reabsorbed. The urine passes from the pelvis of each kidney through the ureters to the urinary bladder. Blood leaves the kidneys through the *renal veins* and returns to the general circulation by way of the *inferior vena cava.* As was said above, the blood in these veins, while it is deoxygenated, is the purest blood in the body.

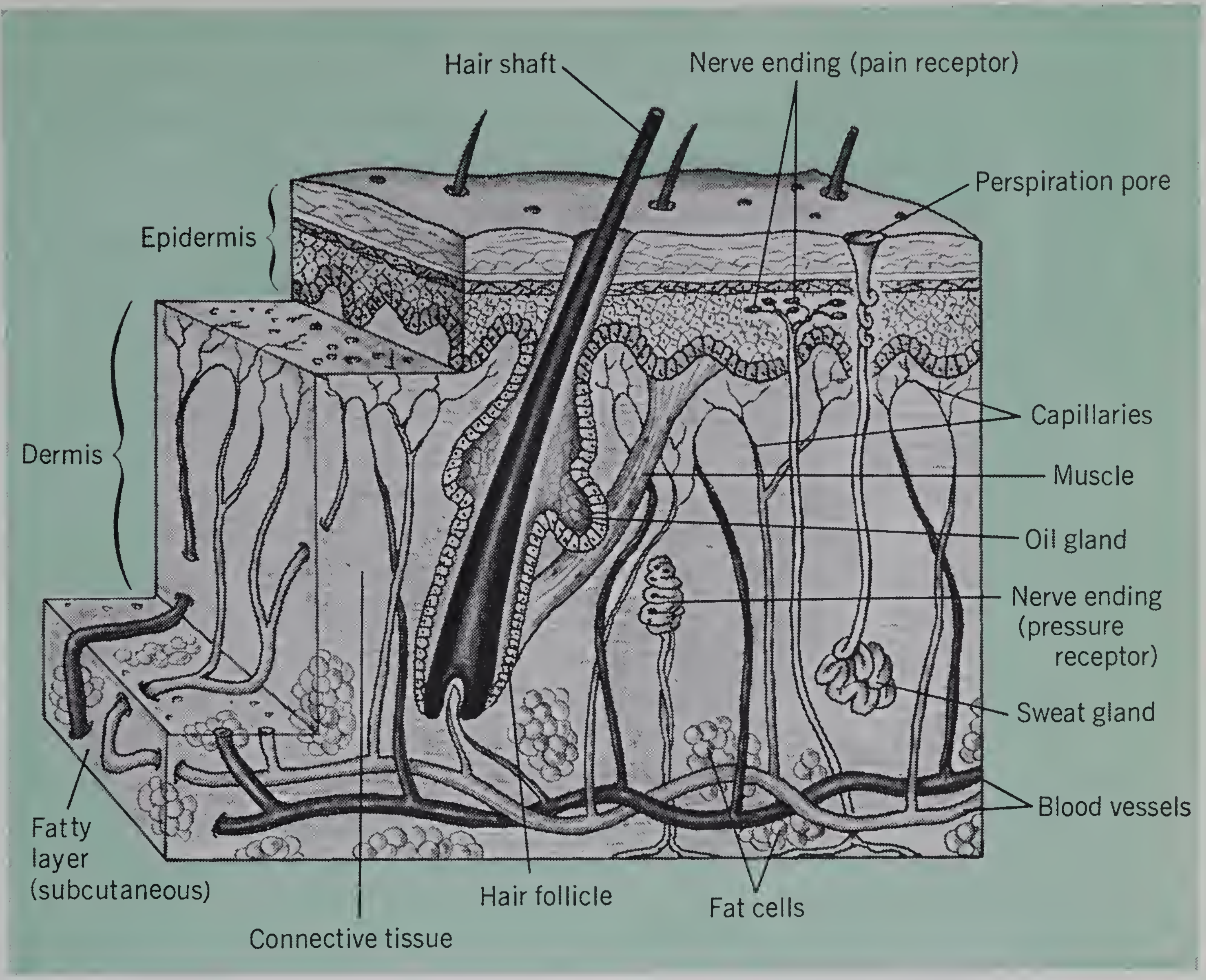
The formation of urine by the kidney is a constant filtration process. After urine leaves the kidneys through the ureters, it collects in the muscular urinary bladder. Contraction of the urinary bladder at intervals expels the urine through the ***urethra*** (yoo-*ree*-thra). The two kidneys have tremendous reserve power. When one is removed, its mate enlarges to twice its normal size and assumes the normal function of two kidneys.

The skin – a supplementary excretory organ. The skin helps the kidneys in the excretion of water, salts, and some urea, in the form of *perspiration.* This fluid is, however, much more important in regulating body temperature than it is as an excretory substance.

Skin consists of an outer portion, or ***epidermis,*** composed of many layers of epithelial cells (Fig. 42–11). The outer cells, or ***horny layer,*** are flattened, dead, and scalelike. The inner ones, or ***germinative layer,*** are more active and larger. The epidermis serves largely for protection of the active tissues beneath it. It is rubbed off constantly, but active cells in the lower layers replace cells as fast as they are lost. Friction and pressure on the epidermis stimulate cell division and may produce a *callus* more than a hundred cells thick. Hair and nails are special outgrowths of the epidermis. The ***dermis*** lies under the epidermis. It is a thick, active layer, composed of tough, fibrous connective tissue, richly supplied with blood and lymph vessels, nerves, sweat glands, and oil glands.

The functions of the skin. The varied functions of the skin include the following:

1. Protection of the body from mechanical injury and bacterial invasion.
2. Protection of the inner tissues against drying out. The skin, aided by oil glands, is nearly waterproof. Little water passes through it, except out through the pores.


Hair shaft
Nerve ending (pain receptor)
Perspiration pore
Epidermis
Dermis
Capillaries
Muscle
Oil gland
Nerve ending (pressure receptor)
Sweat gland
Blood vessels
Fatty layer (subcutaneous)
Hair follicle
Fat cells
Connective tissue

42-11 A thin section of skin shown highly magnified.

3. Location of the nerve endings that respond to touch, pressure, pain, and temperature changes.
4. Excretion of wastes present in sweat.
5. Control of the loss of body heat through the evaporation of sweat.

This last statement needs further explanation. In an earlier discussion about water and its uses, we mentioned that heat is used during the change of liquid water to water vapor. Thus as sweat evaporates from the body surface, heat is withdrawn from the outer tissues. The skin is literally an automatic radiator. It is richly supplied with blood containing body heat withdrawn from the tissues. As the body temperature rises, the skin becomes more flushed with blood, and heat is conducted to the surface. At the same time, secretion of sweat increases and bathes the skin. This increases the rate of evaporation and the amount of heat loss.

Other organs of excretion. During expiration the *lungs* excrete carbon dioxide and considerable water vapor. The excretory function of the *liver* in forming urea has been discussed earlier. The bile stored in the *gallbladder* is also a waste-containing substance.

The large intestine removes undigested food. This, however, is not cell excretion in the strict sense, since the food refuse collected there has never actually been absorbed into the tissues. As you will recall, excretion was defined as the giving off of waste products resulting from metabolism.

IN CONCLUSION

The circulatory system is the transportation system of the body and its vehicle is blood. Blood is a fluid tissue, composed of plasma and solid components. Plasma contains water, blood proteins, prothrombin, inorganic substances, digested foods, and cell wastes. The solid parts of the blood are of three types: red corpuscles, white corpuscles, and platelets. Red corpuscles are essential in carrying oxygen to the body cells and carrying carbon dioxide away as a waste product. White corpuscles aid in fighting disease bacteria. Platelets are an essential factor in the process of blood clotting.

The heart is a pump that forces blood through the arteries to all parts of the body. It consists of two atria, which receive blood from the veins, and two ventricles, which force blood through the arteries by contractions. Arteries carry blood from the heart to the tissues, and veins return it. The arterial and venous systems are connected by countless microscopic networks of capillaries.

Once part of the plasma has seeped into the tissue spaces, it is collected as lymph and filtered by the lymph nodes. Then it is returned to the blood.

Various wastes that result from metabolism are removed from the body through actions of the kidneys, skin, lungs, and liver. The kidneys, the most vital organs of excretion, serve as blood filters. They are responsible for the removal of practically all the nitrogenous wastes resulting from protein metabolism, excess water, and mineral acids and salts. Skin also has a role in excretion and in eliminating heat during evaporation of sweat.

In the next chapter you will learn about respiration, a process that releases energy for the body's use.

BIOLOGICALLY SPEAKING

- a-v valves
- agglutination
- aorta
- aortic sinus
- arteriole
- artery
- atrium
- blood
- Bowman's capsule
- capillary
- circulation
- coronary circulation
- cortex
- dermis
- diastole
- epidermis
- excretion
- germinative layer
- glomerulus
- hemoglobin
- horny layer
- inferior vena cava
- lymph
- medulla
- nephron
- nitrogenous wastes
- pelvis
- pericardium
- plasma
- platelets
- portal circulation
- pulmonary circulation
- pulse
- pyramids
- red corpuscle
- renal circulation
- Rh factor
- s-l valves
- septum
- shock
- solid components
- superior vena cava
- systemic circulation
- systole
- tissue fluid
- tubule
- ureter
- urethra
- urinary bladder
- urine
- vein
- ventricle
- venule
- white corpuscles

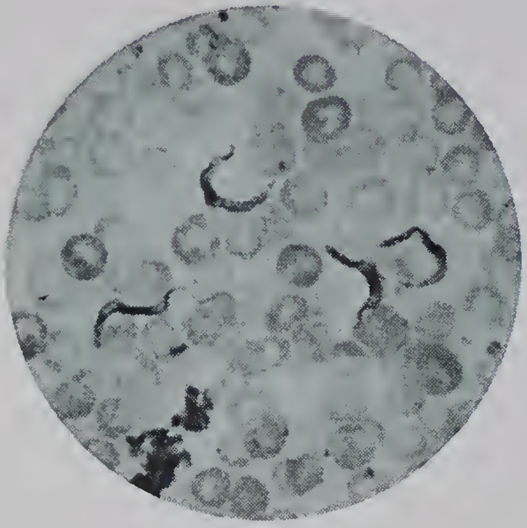
QUESTIONS FOR REVIEW

1. What materials are found in blood plasma?
2. What is the origin of the various blood cells?
3. What condition in the body does a high white-blood count usually indicate?
4. What are the various steps in the clotting of blood?
5. Why is plasma more quickly and easily used in a transfusion than whole blood? Which method do you think is better and why?
6. Trace the path of a drop of blood from the right atrium to the aorta.
7. Name the major circulations which begin at the heart ventricles.
8. Why can you feel the pulse in an artery and not a vein?
9. What is tissue fluid? How does it get back to the blood stream?
10. How does lymph differ from blood?
11. In what way do the kidneys regulate blood content?
12. What are the differences in composition between the glomerular fluid and the urine that finally leaves the kidneys?

APPLYING PRINCIPLES AND CONCEPTS

1. What is the basis for the saying: "A man is as young as his arteries"?
2. Alcohol dilates the arteries in the skin. What would be its effect, then, on the temperature control of the body?
3. Why might a second transfusion with Rh-positive blood be fatal in an Rh-negative patient, while the first transfusion with Rh-positive blood caused no complications?
4. How does the manufacture of red blood cells demonstrate conservation of resources by the body?
5. Why is increased salt intake recommended in hot weather?
6. What happens to water in the blood if it does not enter the glomerulus? if it enters the glomerulus but is reabsorbed? if it enters the glomerulus but is not reabsorbed?

CHAPTER 43



RESPIRATION AND ENERGY EXCHANGE

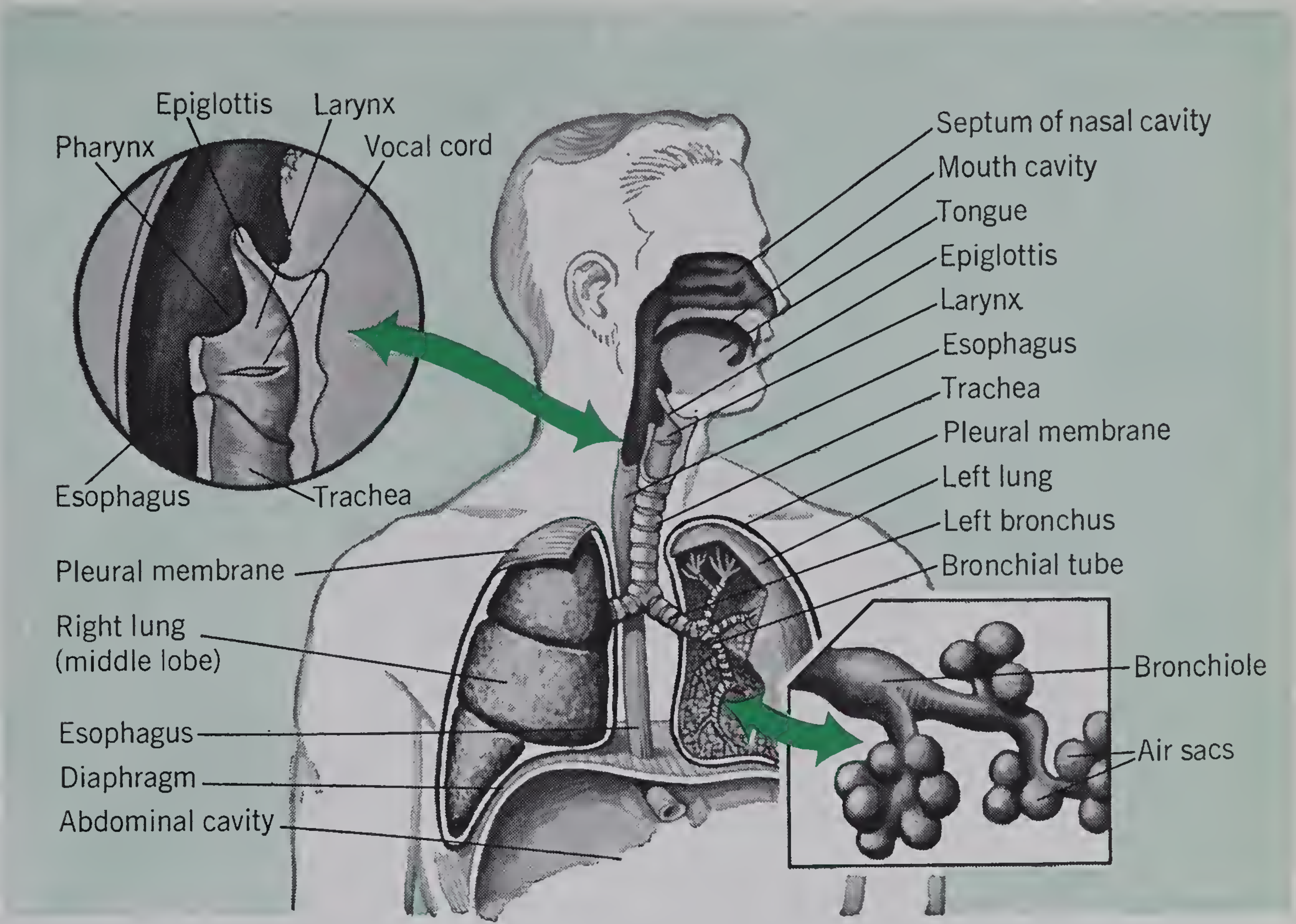
Respiration – a life process common to all living things. Each living cell takes in oxygen, uses it in the oxidation of foods, and gives off carbon dioxide and water. This vital process supplies the cell with energy to carry on its life processes. We may define ***respiration*** as the intake of oxygen and elimination of carbon dioxide associated with energy release in living cells. In some of the simple organisms such as the protists, sponges, and jellyfish, the cells are in direct contact with the environment, and an exchange of gases between the cells and their surroundings occurs directly. Plant cells also respire in this way. In an insect air is delivered directly to the tissues through the tracheae. However, as animals become more complicated in their structure, the cells are deprived of direct contact with the external environment. Some means of receiving oxygen at one place and carrying it to the body tissues becomes necessary.

Two phases of respiration in man. ***External respiration*** concerns the exchange of gases between the atmosphere and the blood. This phase involves the lungs. ***Internal respiration*** concerns the exchange between the blood and the body tissues. It occurs in every living cell. ***Breathing*** is merely a mechanical process involved in getting air that contains oxygen into the body and air that contains waste gases from respiration out of the body.

We can divide the organs concerned with breathing and external respiration into two groups. The first group includes the passages through which air travels in reaching the blood stream: the nostrils, nasal passages, pharynx, trachea, bronchi, bronchial tubes, and lungs (Fig. 43–1). The second group is concerned with the mechanics of breathing by changing the size of the chest cavity. This group includes the ribs and rib muscles, the diaphragm, and the abdominal muscles.

The nose and nasal passages. Air enters the nose through two streams, because the nostrils are divided by the ***septum.*** From the nostrils air enters the nasal passages, which lie above the mouth cavity. The nostrils contain hairs which aid in filtering dirt out of the air. Other foreign particles may lodge on the moist mucous membranes in the nasal passages. The length of the nasal passages warms the air and adds moisture to it before it enters the trachea. All these advantages of nasal breathing are lost in mouth breathing.

The trachea. From the nasal cavity the air passes through the ***pharynx*** (*far*-inks) and enters the windpipe, or ***trachea.***

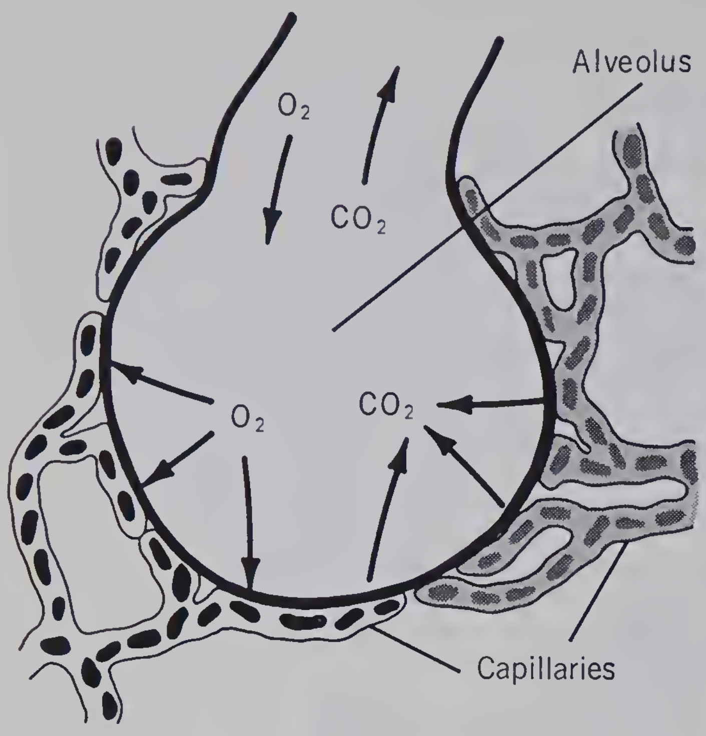

Epiglottis
Larynx
Pharynx
Vocal cord
Esophagus
Trachea
Pleural membrane
Right lung (middle lobe)
Esophagus
Diaphragm
Abdominal cavity
Septum of nasal cavity
Mouth cavity
Tongue
Epiglottis
Larynx
Esophagus
Trachea
Pleural membrane
Left lung
Left bronchus
Bronchial tube
Bronchiole
Air sacs

43-1 The air passages increase in number and decrease in size as they enter the lungs. They end in tiny membranous air sacs. The two enlargements show details of the areas indicated.

The upper end of the trachea is protected by a cartilaginous flap, the ***epiglottis.*** During swallowing the end of the trachea is closed by the epiglottis. At other times the trachea remains open to permit breathing. The ***larynx,*** or "Adam's apple," is the enlarged upper end of the trachea. Inside it are the ***vocal cords.*** The walls of the trachea are supported by horseshoe-shaped rings of cartilage which hold it open for the free passage of air. The trachea and its branches are lined with cilia. These are in constant motion, and carry dust or dirt taken in with air upward toward the mouth. This dust, mixed with mucus, is removed when you cough, sneeze, or clear your throat.

The bronchi and air sacs. At its lower end the trachea divides into two branches called ***bronchi.*** One extends to each lung and subdivides into countless small ***bronchial tubes.*** These in turn divide into many small tubes called ***bronchioles,*** which end in ***air sacs.*** These air sacs are composed of protrusions called ***alveoli*** and compose most of the lung tissue. The walls of the air sacs are very thin and elastic. Through their thin walls gases are exchanged between the capillaries and the air sacs (Fig. 43–2). Thus the lungs provide enough surface to supply air by way of the blood for the needs of millions of body cells having no direct access to air. The total area of the air sacs in the lungs is about 2,000 square feet, or more than 100 times the body's surface area.

The ***lungs*** fill the body cavity from the shoulders to the diaphragm, except



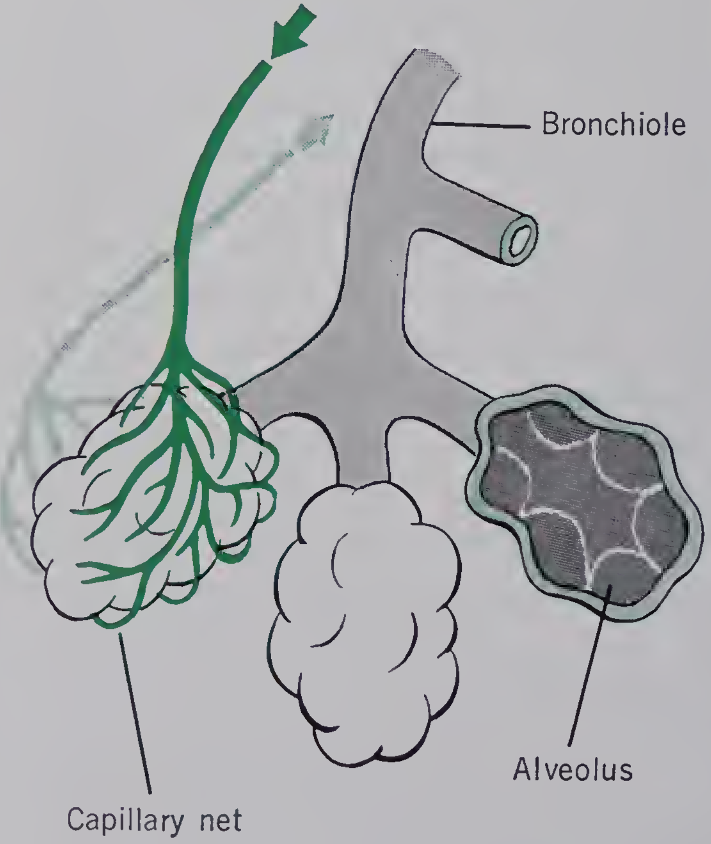
43-2 This diagram represents external respiration and shows an enlargement of a single alveolus. The solid oval structures in the capillaries represent red blood corpuscles.

for the space occupied by the heart, trachea, esophagus, and blood vessels. They are spongy and consist mainly of the bronchioles and air sacs and an extensive network of blood vessels and capillaries, held together by connective tissue. The lungs are covered by a double ***pleural membrane.*** One part adheres tightly to the lungs, and the other covers the inside of the thoracic cavity. These membranes secrete lubricating mucus so that there is free motion of the lungs in the chest for breathing.

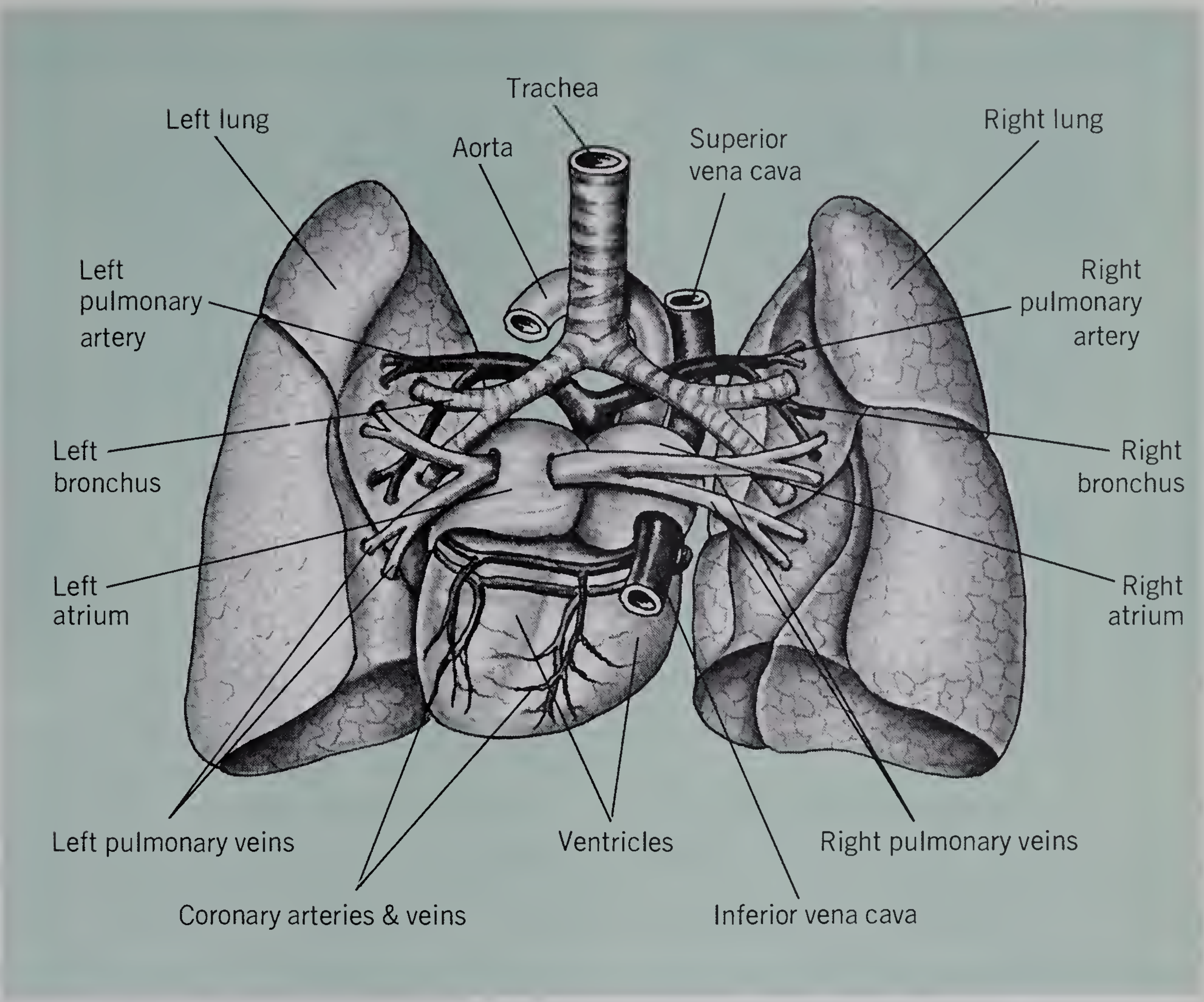
Gas exchange in the lungs. The *pulmonary artery* brings dark (deoxygenated) blood to the lungs. There it divides into an extensive network of capillaries, completely surrounding each air sac (Fig. 43–3). The thin moist walls of both air sac and capillary aid the gaseous exchange of oxygen from air to blood and of carbon dioxide and water from blood to air. The *pulmonary veins* return to the heart the bright (oxygenated) blood for the tissues.

The concentration of oxygen in the air sacs of the lungs is higher than that in the lung capillaries. Hence oxygen is absorbed by the lung capillaries where it combines with the hemoglobin of the red blood corpuscles. In the tissues, where the concentration of oxygen is low, hemoglobin releases its oxygen. The affinity of hemoglobin for oxygen decreases with increasing acidity. This is an important characteristic, because during violent exercise lactic acid is produced by the active muscle cells. This increases the acidity of the blood and causes the hemoglobin to release more of its oxygen than it would normally.

The movement of carbon dioxide and water in the lungs is the opposite of that of oxygen. Carbon dioxide and water in the lung capillaries have a higher concentration than in the connecting air sacs. Hence they diffuse outward into the area of lower concentration in the air sacs, and are exhaled.



43-3 Three clusters of alveoli. Refer to Fig. 43-2 for an enlargement of one alveolus.

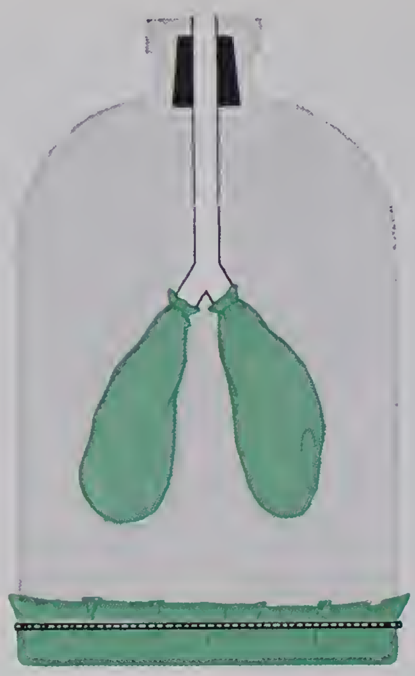

Trachea
Left lung
Aorta
Superior vena cava
Right lung
Left pulmonary artery
Right pulmonary artery
Left bronchus
Right bronchus
Left atrium
Right atrium
Left pulmonary veins
Ventricles
Right pulmonary veins
Coronary arteries & veins
Inferior vena cava

43-4 In this back view of the lungs and heart, you can see the branches of the pulmonary artery and the pulmonary veins. Which vessels are carrying oxygenated blood?

The mechanics of breathing. Many people think that the lungs draw in air, expand, and bulge the chest. Actually this is the opposite of what happens. The lungs contain no muscle, and cannot expand or contract of their own accord. They are spongy, air-filled sacs, anchored in the chest cavity. Breathing is accomplished by changes in size and air pressure of the chest cavity. This fact can be shown by substituting apparatus for the body parts (Fig. 43–5).

A Y-tube (trachea and bronchi) is inserted in a stopper and set in a bell jar (chest). Balloons (lungs) are fastened to the Y-tube. A piece of rubber sheet (diaphragm) is fastened securely to the open base of the bell jar. When you pull the rubber sheet downward, you increase the volume of the bell jar and decrease the pressure within it. Air moves through the Y-tube and inflates the balloons. When you release the rubber sheet, the volume of the bell jar is decreased and the pressure within it is increased. Again air moves to equalize the pressure. But this time it leaves the balloons and passes through the Y-tube to the atmosphere.

Although the apparatus described above is a good model, notice that only one thing is being changed — the rubber sheet representing the diaphragm.



43-5 Identify the parts of the respiratory system that are represented in this apparatus. What breathing structures are *not* properly represented?

As you will see, the ribs also play an important part in changing the size and pressure of the chest cavity.

Breathing movements. ***Inspiration,*** or intake of air, occurs when the chest cavity is increased in size and therefore decreased in pressure. Enlargement of the chest cavity involves the following movements:

1. The rib muscles contract and pull the ribs upward and outward. If you inhale with force, you carry this action even further with the aid of the shoulder muscles.
2. The muscles of the resting, dome-shaped diaphragm contract. This action straightens and lowers the diaphragm and increases the size of the chest cavity from below.
3. The abdominal muscles relax and allow compression of the abdominal organs by the diaphragm.

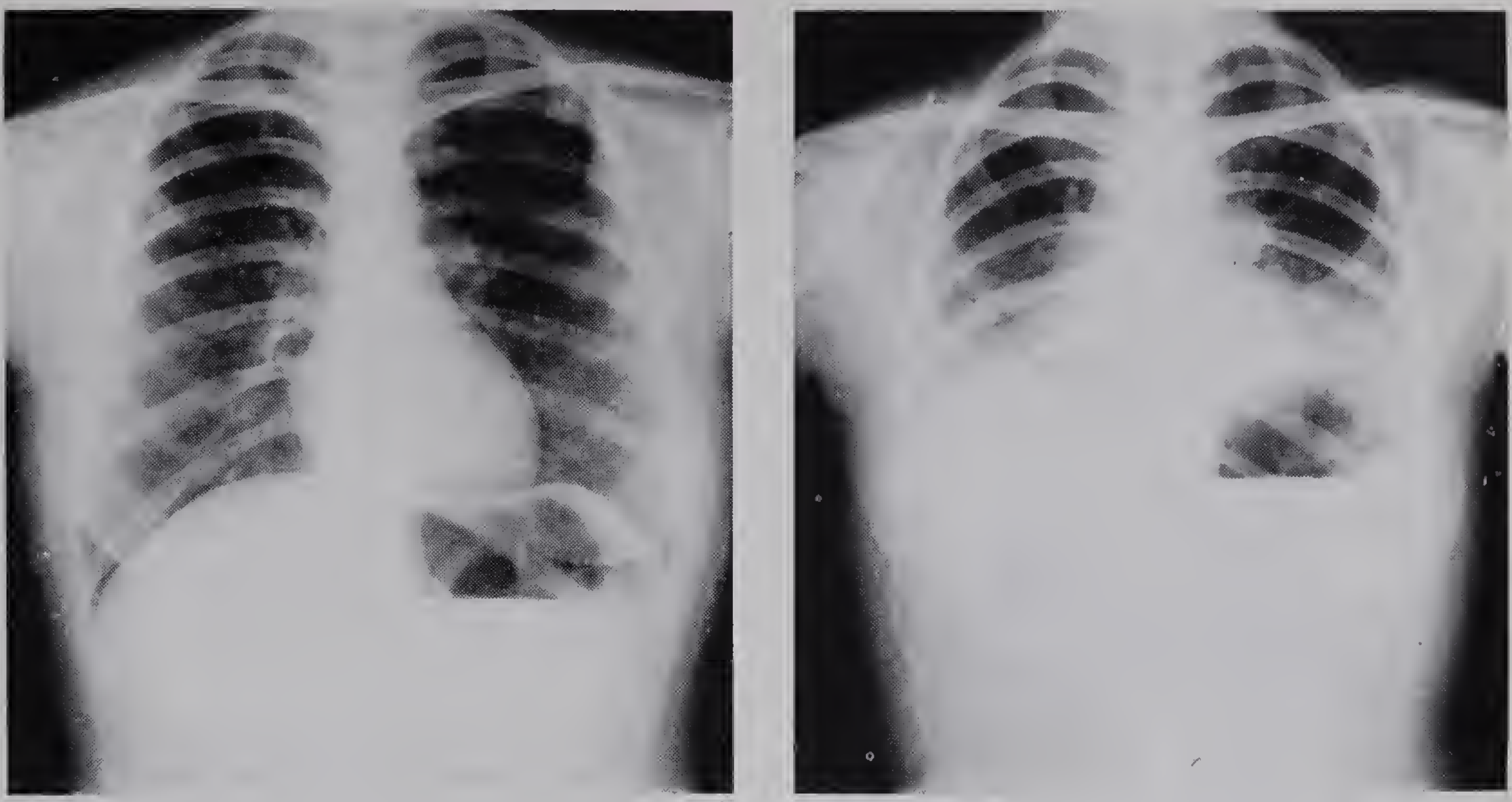
The enlargement of the chest cavity results in decrease of the air pressure within. In an equalizing of outer and inner pressure, air passes down the trachea and inflates the lungs.

Expiration, or the expelling of air from the lungs, results when the chest cavity is reduced in size. The action involves the following four movements:

1. The rib muscles relax and allow the ribs to spring back.
2. The diaphragm relaxes and rises to assume its dome-shaped position.
3. The compressed abdominal organs push up against the diaphragm. This action is increased during forced exhalation by contraction of the abdominal muscles.
4. The elastic lung tissues, stretched while the lungs are full, shrink and force air out.

The control of breathing. The factors that control breathing and breathing rate are both nervous and chemical. There are nerves leading from the lungs, diaphragm, and rib muscles to a respiratory control center at the base of the brain. When the lungs expand in inspiration, impulses pass from nerve endings in their tissues along the nerve leading to the control center. The control center in turn sends impulses to the rib muscles and diaphragm, causing them to return to their resting position in the act of expiration. When expiration is complete, the process is reversed and the control center sends impulses to the rib muscles and diaphragm that cause them to contract, so that the lungs expand, and the cycle starts again. Inspiration and expiration occur from 16 to 24 times per minute, depending on the body activity, position, and age.

The air capacity of the lungs. When the lungs are completely filled they hold about 300 cubic inches of air. But only about 30 cubic inches are involved each time we inhale and exhale. The air involved in normal, relaxed breathing is called *tidal air.* Forced breathing increases the amount of air movement.



43-6 These two X-ray photographs show the chest during exaggerated breathing. The left-hand one represents inhalation; the right one represents exhalation.

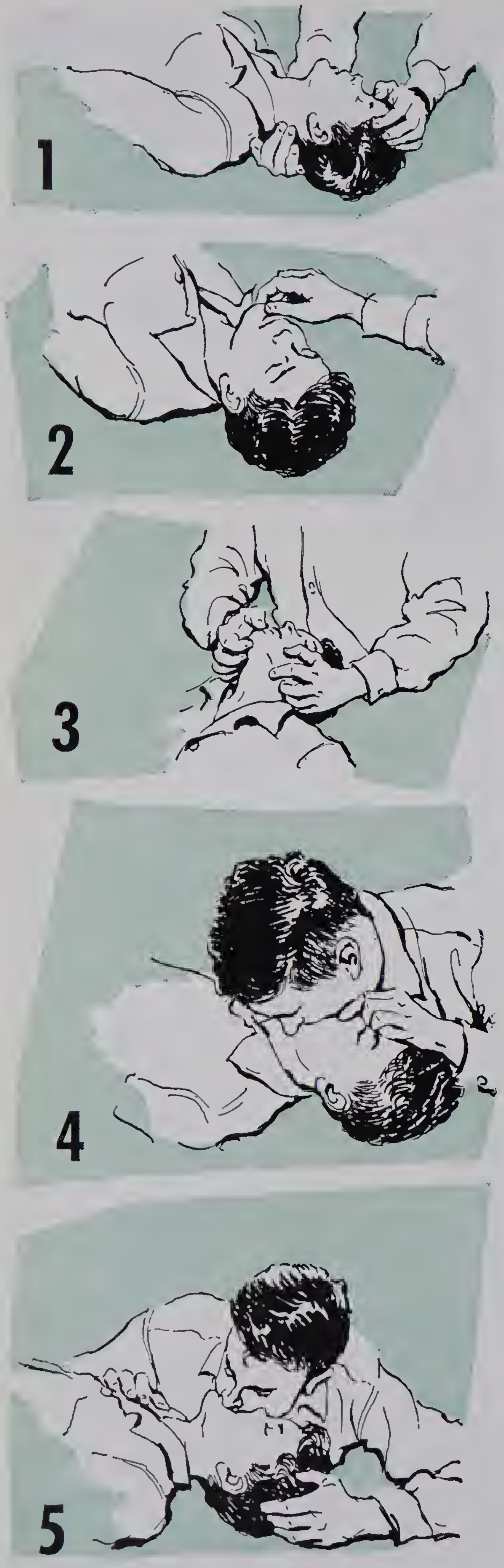
To illustrate the effects of forced breathing, inhale normally without any forcing. Your lungs now contain about 200 cubic inches of air. Now exhale normally. You have moved about 30 cubic inches of tidal air from the lungs. Now, without inhaling again, force out all the air you can. You have now exhaled an additional 100 cubic inches of *supplemental air*. The lungs now contain about 70 cubic inches of *residual air*, which you cannot force out.

When you inhale normally again, you replace the supplemental and the tidal air, or about 130 cubic inches. If you inhale with force you can add 100 cubic inches of *complemental air*, raising the total capacity of the lungs to about 300 cubic inches. We can say the *total capacity* of the lungs consists of:

Tidal air	30 cu. in.
Supplemental air	100 cu. in.
Complemental air	100 cu. in.
Residual air	70 cu. in.
Total capacity	300 cu. in.

Artificial respiration. Any stopping of the breathing motions can be serious because the blood will then lack oxygen and the cells will suffer. *Artificial respiration* is simply a method of artificially forcing the lungs to inspire and expire air rhythmically. It can be described more accurately as *artificial breathing.* The *back pressure-arm lift method* is one approved by the American Red Cross. A more recent method now strongly recommended by the Red Cross is the *mouth-to-mouth method,* shown in Fig. 43–7. This method gets more air into the victim's lungs than any other method of artificial respiration. The operator places his mouth over the mouth or nose of the victim and breathes into the victim until he sees the chest rising. The rate at which this is repeated depends on whether the victim is an adult or a child.

Paying off a debt. In the tissues, oxygen is used by each cell in the oxidation of food to release energy. This process is especially rapid in active muscle tissue.



43-7 Mouth-to-mouth artificial respiration. Before starting the mouth-to-mouth method of artificial respiration, look to see if there is any foreign matter in the victim's mouth. If so, wipe it out with your fingers, then proceed according to the following steps:

First, tilt the head back so the chin is pointing upward (*1*). Pull or push the jaw into a jutting-out position (*2* and *3*). These maneuvers should relieve obstruction of the airway by moving the base of the tongue away from the back of the throat.

Second, open your mouth wide and place it tightly over the victim's mouth. At the same time pinch the victim's nostrils shut (*4*) or close the nostrils with your cheek (*5*). Or close the victim's mouth and place your mouth over his nose. Blow into the victim's mouth or nose.

Third, remove your mouth, turn your head to the side, and listen for the return rush of air that indicates air exchange. Repeat the blowing effort. For an adult, blow vigorously at the rate of 12 breaths per minute. For a child, take relatively shallow breaths appropriate for the child's size at the rate of about 20 per minute.

Fourth, if you are not getting air exchange, recheck the head and jaw position. If you still do not get air exchange, quickly turn the victim on his side and administer several sharp blows between the shoulder blades to dislodge any foreign matter in the airway. (Redrawn from American Red Cross)

When sufficient oxygen is supplied to muscle tissues, it combines with hydrogen released during fuel breakdown and forms water. This water, together with carbon dioxide released as a fuel by-product, is discharged as a waste product of aerobic respiration.

During times of muscular exertion, the need for oxygen in the tissues is greater than the body can possibly supply. The lungs cannot take in oxygen nor can the blood deliver it rapidly enough. All of us at some time or another have had the experience of running or swimming in a race, playing tennis, climbing a mountain, or running to board a train or a bus. Perhaps you can remember feeling, for a second, that you just couldn't finish that race or catch that bus. But with a final surge of reserve energy, you succeeded. You felt limp, lightheaded, and completely exhausted. You may recall how your heart pounded and your breathing was deep and rapid. After 20 or 30 minutes you were probably ready for another race, another tennis match, or the long hike back.

What happens in one's body to cause these changes, and how is this rapid recovery brought about? During mild exercise the supply of oxygen meets the demands of the cells. During exertion, however, there is not enough oxygen. Then, respiration becomes anaerobic and pyruvic acid becomes the hydrogen acceptor. This produces *lactic acid,* which accumulates in the tissues and causes fatigue. Like carbon dioxide, lactic acid signals the respiratory center in the brain. Breathing becomes rapid and the heart speeds up in order to supply the tissues with enough oxygen. As you learned above, hemoglobin releases more oxygen because of the acidity of the blood. But even with these efforts, the lactic acid accumulates in the body, and the body is in a state of *oxygen debt.* During a half-hour rest, some of the accumulated lactic acid is oxidized, and some is converted to glycogen. Carbon dioxide and excess water are excreted, and the debt is paid. The body is then ready for more exercise.

43-8 During excessive muscular exercise such as a track event, a considerable oxygen debt is built up. How and when is this debt paid off? (Shelton from Monkmeyer Press Photo Service)

Body metabolism and its measurement. In Unit One you learned that the sum of all the processes occurring in a cell or an organism is called metabolism. The constructive phase of metabolism includes carbohydrate and protein synthesis, while the destructive phase includes oxidation and energy release. The rate of metabolism increases in proportion to the activity of the body. This activity may be muscular, as in walking, running, or some other form of exertion, or it may be mental. Other factors governing the metabolic rate include exposure to cold and activity of the digestive organs during digestion of food. One way to measure the metabolic rate of the body is to measure the rate of oxidation by determining the amount of heat given off from the body surface. This may be measured by a device called a *calorimeter.*

The person to be tested enters a closed compartment that is equipped to accurately measure all the heat given off by his body. He may lie quietly in bed during the process, or he may sit in a chair, or exercise vigorously, depending on the nature of the activity to be tested. The amount of heat energy given off during each type of activity is a direct indication of the rate of oxidation in the body tissues. Calorimeter tests are important in determining the energy needs of various individuals in order to adjust a diet to their specific requirements.

Even when the body seems completely inactive, as it does in sleep, respiration, oxidation, and energy release are continuing. With the cessation of muscular and, to a great extent, nervous activity, the rate of oxidation is greatly reduced. The activities required to maintain the body and to supply energy necessary to support the basic life processes are included in the term *basal metabolism.* The rate at which these activities occur is termed the *basal metabolic rate,* or **BMR.**

BMR may be determined by means of the calorimeter test. Another method, widely used in hospitals, measures the amount of oxygen consumed in a definite period (Fig. 43–9). The patient rests for at least an hour before the test. The test is usually run in the morning, and the patient is instructed to eat no food until after the test is completed. After a test period, during which the body is completely relaxed, the nose is plugged to avoid breathing from the atmosphere. A mouthpiece connected to a tank of oxygen is fitted into the mouth. Thus all oxygen inhaled during the test period is from the measured tank. The amount of oxygen used from the tank is recorded on a graph. From these data the rate of oxidation is determined. The rate of basal metabolism is calculated from the rate of oxidation in the tissues during complete rest.

External influences on breathing and respiration. External factors such as temperature, moisture in the air, and oxygen and carbon dioxide content of air, are very important influences on the rate of breathing and respiration. Certain of these factors are involved in *ventilation.* Stuffiness in a room is due mainly to increase in the temperature and moisture content of the air, rather than to accumulation of carbon dioxide

43-9 A basal metabolism test determines the rate at which oxidation occurs in the body. (Sanborn Co.)

and decrease of the oxygen content. Movement of air in a ventilating system increases its flow over the body surfaces and speeds up the evaporation of perspiration. Modern air-conditioning systems not only circulate air but remove moisture and heat as well.

The air in most homes, especially those equipped with a central heating system, becomes too dry during the cold months. This condition dries out mucous membranes and lowers their resistance to infection. For this reason the moisture content of the air should be kept as high as possible by means of humidifiers or other devices.

Many people carry the ventilation of bedrooms at night to extremes. Your body requires less oxygen while you are asleep than at any other time. If the windows are open too much during cold weather, your body may chill during the night. There is little logic in piling covers on a bed to keep part of the body warm while at the same time chilling the exposed parts with cold air from an open window.

Carbon-monoxide poisoning. Far too often we read of people who have died in a closed garage where an automobile engine was running or in a house filled with gas from an open stove burner or a defective furnace. The cause of death is given as *carbon-monoxide poisoning.* Actually the death is not due to poisoning but to *tissue suffocation.* Carbon monoxide will not support life. Yet it combines with the hemoglobin of the blood 250 times more readily than oxygen. As a result the blood becomes loaded with carbon monoxide and decreases its oxygen-combining power. As tissues suffer from oxygen starvation, the victim becomes lightheaded and ceases to care about his condition. Soon paralysis sets in, and he cannot move even if he wants to. Death follows from tissue suffocation.

43-10 This spaceman's suit has been designed to provide a comfortable level of pressure and oxygen for high-altitude flying. (National Aeronautics and Space Administration)

Respiration problems at high altitudes. At sea level the air pressure remains at approximately 14.7 pounds per square inch. In a sense we are living at the bottom of a large sea of air. With increased altitude the amount of air pressure is reduced. The pressure of the air is an important factor in breathing and in how oxygen combines with the hemoglobin of the blood. For this reason mountain climbers and airplane pilots experience increasing difficulty in breathing and progressive weakness as they increase their altitude. At elevations near 12,000 feet many people fatigue easily.

A pilot can fly much higher than a man can climb because the plane motor is doing the work. But when a pilot nears 20,000 feet, the pressure becomes so reduced that he experiences difficulty in seeing and hearing. This condition, called *anoxia*, is the result of oxygen starvation in the tissues. It will cause death if not corrected within a short time. Anoxia may be avoided by equipping the pilot with an oxygen tank and a mask.

Passengers in modern airliners can fly at high altitudes in the safety and comfort of pressurized cabins. These cabins maintain an internal pressure and oxygen content equivalent to an altitude of approximately 5,000 feet.

Respiration – a vital problem in space travel. The astronaut encounters the problems of people at high altitudes to a much greater degree. At 16 miles above the earth, the density of the air is only about 4 percent of its density at sea level; beyond an altitude of 70 miles there is practically no atmosphere and therefore practically no oxygen. It is now known, however, that after training, man can exist in an atmosphere of about half the normal oxygen content on earth without discomfort, and still be reasonably efficient. Investigators learned this by studying a tribe of Indians who live at high altitudes in the mountains of Peru. These Indians are able to carry on normal physical activities that would quickly exhaust a healthy person accustomed to the atmosphere at sea level. On further investigation the scientists learned that these tribesmen have greater lung capacity and a higher red blood cell count. They are able to take in more air with each breath, and the extra red cells distribute oxygen more efficiently. Space scientists have found that similar changes occur in men trained in an atmosphere of reduced oxygen. But even for trained astronauts, the entire cabin of a spaceship must be supplied with oxygen or the astronauts must wear masks connected to oxygen tanks and pressure suits.

On earth the carbon dioxide in the atmosphere is used by plants in the process of photosynthesis. In a sealed spaceship, however, it is necessary to dispose of the carbon dioxide exhaled by the travelers. Algae are now being considered for use in prolonged space travel. The green alga *Chlorella* shows promise because of its high photosynthetic rate and rapid reproduction. *Chlorella* may also serve as an excellent source of oxygen to replenish the supply on the spaceship. There is also the possibility that *Chlorella* can serve as a source of food for the passengers.

IN CONCLUSION

Respiration involves the exchange of gases between living matter and its surroundings and the chemical process of oxidation, in which energy is released during the breakdown of foods. In lower forms of life individual cells are in direct contact with their surroundings. In higher animals blood is the conducting medium between the body tissues and respiratory organs in contact with the outer environment. The movement of air in and out of lungs is accomplished by the mechanical process known as breathing, which consists of inspiration and expiration. External respiration and internal respiration are concerned respectively with the actual exchange of gases between the lungs and blood and between the blood and body tissues.

Metabolism includes respiration, oxidation, and the growth processes. The rate at which these processes occur during rest is expressed as the basal metabolic rate.

In the next chapter we shall examine other processes that are controlled by the nervous system, and we shall see how various stimuli are received.

BIOLOGICALLY SPEAKING

air sacs
alveoli
BMR
breathing
bronchi
bronchial tubes
bronchioles
epiglottis
expiration
external respiration
inspiration
internal respiration
larynx
pharynx
pleural membrane
respiration
septum
trachea
vocal cords

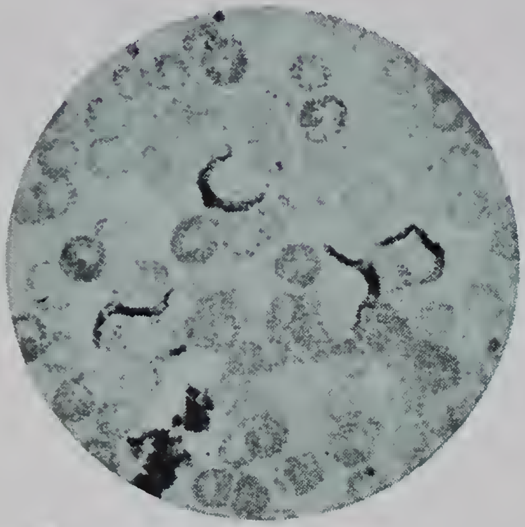
QUESTIONS FOR REVIEW

1. What are the differences between respiration and breathing?
2. List the major organs of the respiratory system.
3. Describe gas exchange in the lungs, naming the structures involved and explaining why the exchange occurs.
4. How do pressure changes within the chest cavity cause inspiration and expiration?
5. What factors influence the rate of breathing?
6. What is the purpose of artificial respiration?
7. How do you build up an oxygen debt? How is it repaid?
8. Define BMR and give two ways in which it may be measured.
9. Explain the physiology of carbon-monoxide poisoning.
10. Compare respiration problems encountered on a high mountain to those in space travel.

APPLYING PRINCIPLES AND CONCEPTS

1. If plants produce oxygen in photosynthesis, how do you explain the fact that they also respire?
2. What changes would you expect to occur in the blood if you were to hold your breath for a period of time? if you were to breathe rapidly and deeply for a period of time?
3. People who live in dry climates, such as the southwestern parts of our country, report that high temperatures there are easier to take than the same temperatures in the more humid parts of the United States. Why?

CHAPTER 44



BODY CONTROLS

The nervous system. Your nervous system receives impressions from your surroundings, stores them in the brain, originates activity, and carries impulses to all parts of the body. It coördinates the activity of several million cells into a single functioning unit — the control center for body activities. The nervous system's activities involve impulses carried along nerves in a two-way communication system. Impulses are sent from the body tissues and organs to nerve centers, and from these centers to the tissues and organs.

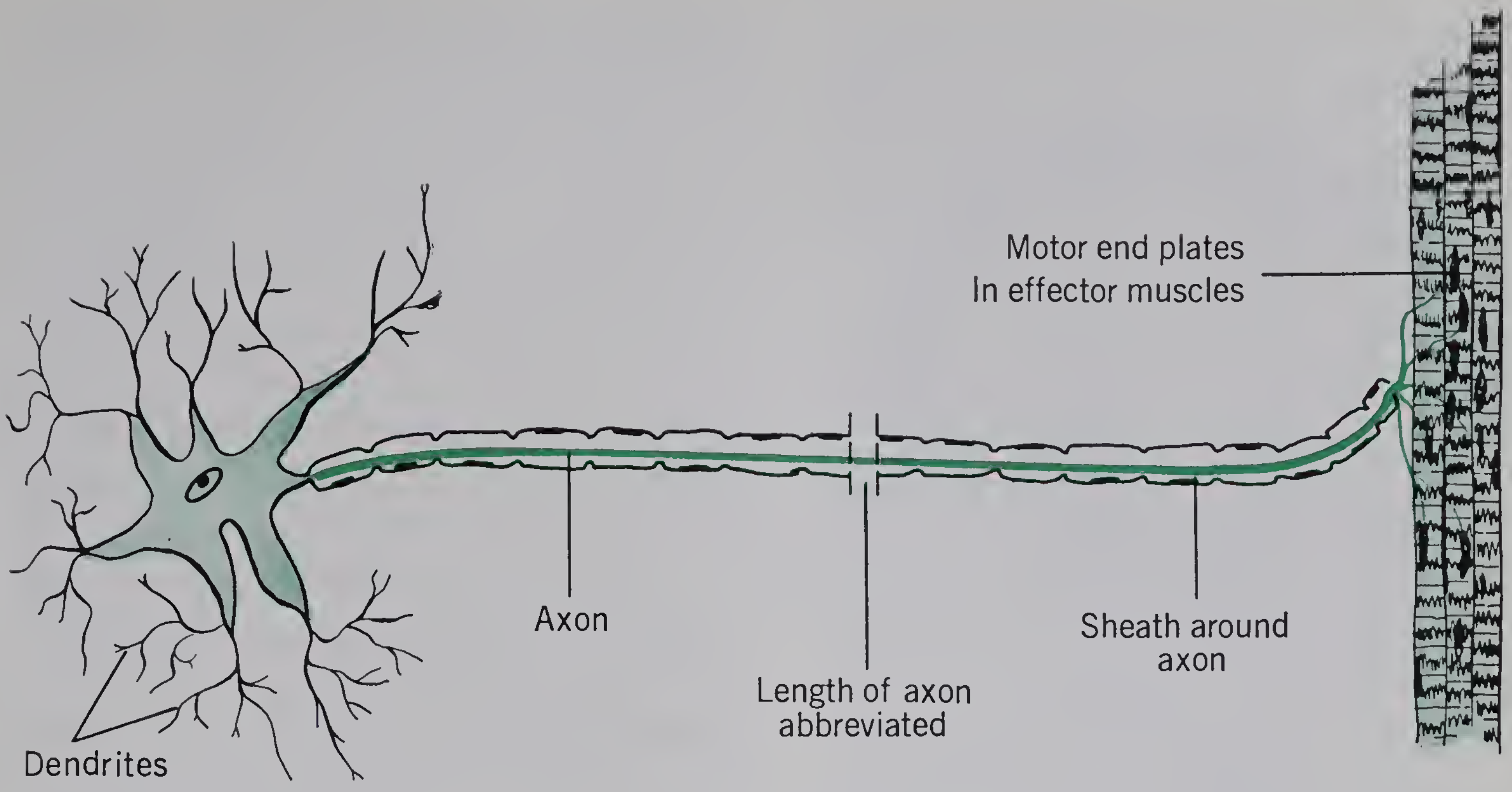
The brain and spinal cord comprise the *central nervous system.* They communicate with all parts of the body by means of the nerves of the ***peripheral system.*** Another division is the ***autonomic system,*** which regulates certain vital functions of the body almost independently of the central nervous system.

The nerve cell. Nerve cells are called ***neurons.*** Each has a rounded, star-shaped or irregular cell body, containing a nucleus and cytoplasm, from which threadlike processes, often called *nerve fibers,* extend (Fig. 44–1, page 613). The branching treelike fibers that carry impulses *to* the cell body are called ***dendrites.*** The number of dendrites entering a cell body may range from one to 200. Impulses travel *from* the cell body along a single fiber. These outgoing processes are called ***axons.*** Dendrites and axons branch at their tips in tiny brushlike structures. The fibers of many brain cells are short. Those leading from the spinal cord to muscles and glands, however, may be half as long as your body.

Impulses travel along nerve fibers in one direction only. The fibers of ***sensory neurons*** always carry impulses *to* the brain or spinal cord. Those of ***motor neurons*** always carry impulses *from* the brain or spinal cord. The endings of sensory and motor neurons in the spinal cord and brain mingle with many ***central neurons*** that have short processes.

The processes of one neuron never touch those of another neuron. The space between endings of neuron processes is called a ***synapse*** (*sin*-aps). Impulses must pass over these synapses as they travel from one neuron to another. Furthermore, an impulse never travels from one motor neuron to another. It is received by the dendrite of a sensory or a central neuron. Nor do impulses travel from one sensory neuron to another.

The threadlike ***nerves*** that branch through your body are bundles of fibers arranged like wires in a cable. In the peripheral nervous system, any nerve composed only of the fibers of motor



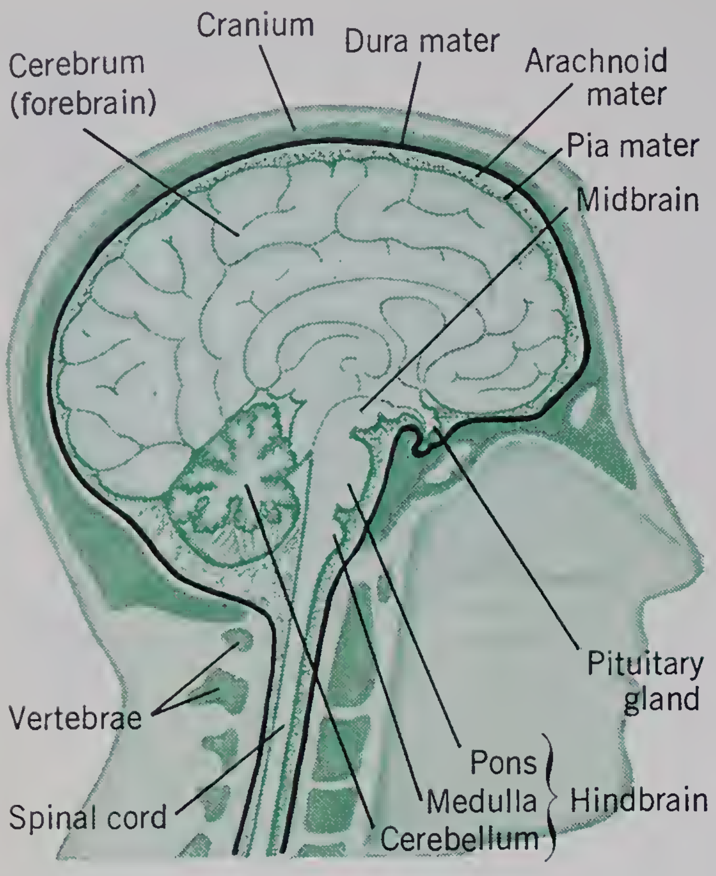
44-1 This drawing represents a typical motor neuron.

neurons is a *motor nerve.* Any nerve composed only of the fibers of sensory neurons is a *sensory nerve.* Some nerves contain both motor and sensory fibers, and are called *mixed nerves.* If all the body tissues other than nervous tissue were dissolved, the outline of the body would be preserved by the nerves that would remain.

Nerve impulses. A ***nerve impulse*** is known to be an electrochemical impulse, which brings about a change in the nerve fiber. It is not a flow of electricity, for nerve impulses are much slower. A nerve impulse travels at a rate of about 300 feet per second, while electricity travels at a rate of 186,000 miles per second. Also, when a nerve impulse passes along a nerve, carbon dioxide is liberated, which indicates that a chemical reaction is involved.

For a long time scientists were in doubt as to how a nerve impulse causes a muscle to contract. Now we know that the stimulation is indirect. An impulse traveling along the axon of a motor neuron ends at the *motor end plate* at the tips of the brushlike structures. Here the impulse causes the release of a minute amount of a chemical called *acetylcholine* (a-*seet*-il-*koh*-leen). This substance transmits the impulse to muscle fibers, which begin the process of contraction we discussed in Chapter 40. Following a brief period of contraction, the nerve releases another substance, *cholinesterase* (koh-li-*nes*-te-rays), which neutralizes acetylcholine and causes the muscle fibers to relax, all in 0.1 second or less.

The brain and its membranes. The brain (Fig. 44–2) is probably the most highly specialized organ of the human body. It weighs about three pounds and fills the cranial cavity. It is composed of soft nervous tissue covered by three membranes, together known as the ***meninges*** (meh-*nin*-jeez). The inner membrane, or *pia mater* (*pee*-a *mah*-ter), is richly supplied with blood vessels which carry food and oxygen to the brain cells. It is a delicate membrane which closely adheres to the surface of the brain and into all the grooves. The middle membrane, or *arachnoid mater,* consists of fibrous and elastic tissue. This mem-



44-2 Longitudinal section of the brain showing the regions and the meninges.

brane does not dip down into the grooves of the brain but bridges them. The space between these two membranes is filled with a clear liquid, the ***cerebrospinal fluid***, which, as the name implies, is also found around the spinal cord. The outermost layer of protective membranes is a thick, strong, fibrous lining, the *dura mater*. This layer serves as a lining for the inside of the cranium as well as a membrane of the brain. The meninges protect the brain from jarring by acting as a cushion. A *concussion* is a brain bruise resulting from a violent jar that causes damage in spite of the protective meninges. These three membranes extend down the spinal column to cover and protect the spinal cord.

Cavities of the brain. There are four spaces called ventricles within the brain. Two *lateral ventricles* open into the *third ventricle*, which leads to the *fourth ventricle*. From the fourth ventricle the cavity is continuous with the *subarachnoid space* and the central canal of the spinal cord. The cavities of the brain and the central canal are lined with ciliated epithelium, which keeps the cerebrospinal fluid, with which the cavities are filled, in motion.

The cerebrum – the largest of the brain regions. The region of the brain called the ***cerebrum*** is proportionally larger in man than in any animal. It consists of two halves, or hemispheres, securely joined by tough fibers and nerve tracts. The outer surface, or *cortex*, is deeply folded in irregular wrinkles and furrows, the *convolutions*, which greatly increase the surface area of the cerebrum. Deeper grooves divide the cerebral cortex into lobes (Fig. 44–3).

The cerebral cortex is composed of countless numbers of neurons. We frequently refer to this area as gray matter because of the color of these cells. The cerebrum below the cortex is composed of white matter, formed by masses of fibers covered by sheaths and extending from the neurons of the cortex to other parts of the body.

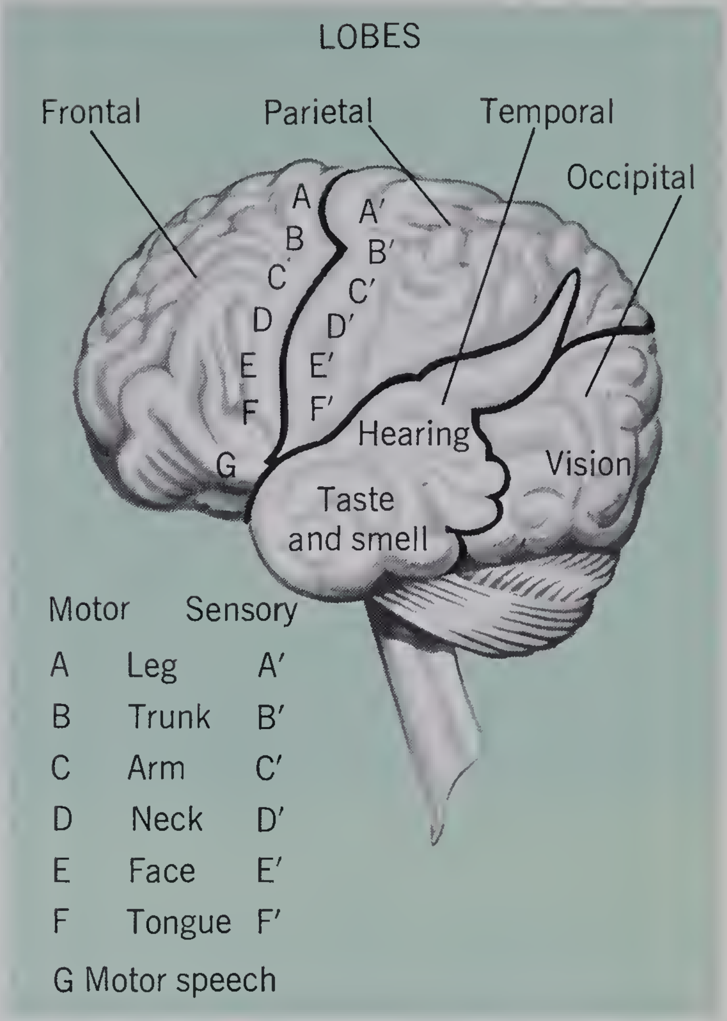
The functions of the cerebrum. Different activities are controlled by specific regions of the cerebrum. Some of the areas of the cerebral cortex are *motor areas*, which means that they are centers that control voluntary movement. The motor area of the cerebrum controls the muscles of the legs, trunk, arms, shoulders, neck, face, and tongue in this order, from the top of the lobes downward. Some of the areas of the cerebral cortex are *sensory areas*, which means that the various senses, such as seeing, hearing, touching, tasting, and smelling, are interpreted here. For example, we interpret what our eyes see in the vision center of the *occipital* (ahk-*sip*-it-l) *lobes*. If these lobes were destroyed, we would not be able to see anything, although our eyes might be perfect. We know also that the *frontal lobes* are centers of emotion, judgment, will power, and self-control. These functions, however, are shared by other areas of the cerebral cortex.

The things we see and hear and feel are registered as impressions in the sensory areas of the cerebral cortex. The things we do are controlled by the motor areas. These areas are in turn connected by a vast number of *association areas*. Thoughts are the result of associations of impressions. Your intellectual capacity is determined by the ability of your cerebral cortex to register impressions, the activity of your association areas, and the sum of your past experiences.

The functions of the cerebellum. The ***cerebellum*** is a structure lying below the back of the cerebrum. Like the cerebrum it is composed of hemispheres, but its convolutions are shallower and more regular than those of the cerebrum. The surface of the cerebellum is composed of gray matter. Its inner structure is largely white matter, although it contains some areas of gray matter. Bundles of nerve fibers connect the cerebellum with the rest of the nervous system.

In a sense the cerebellum acts as an assistant to the cerebrum in controlling muscular activity. Nervous impulses do not originate in it nor can one control its activities. The chief function of the cerebellum is to coordinate the muscular activities of the body. Thus, without the help of the cerebellum, the impulses from the cerebrum would produce uncoordinated motions.

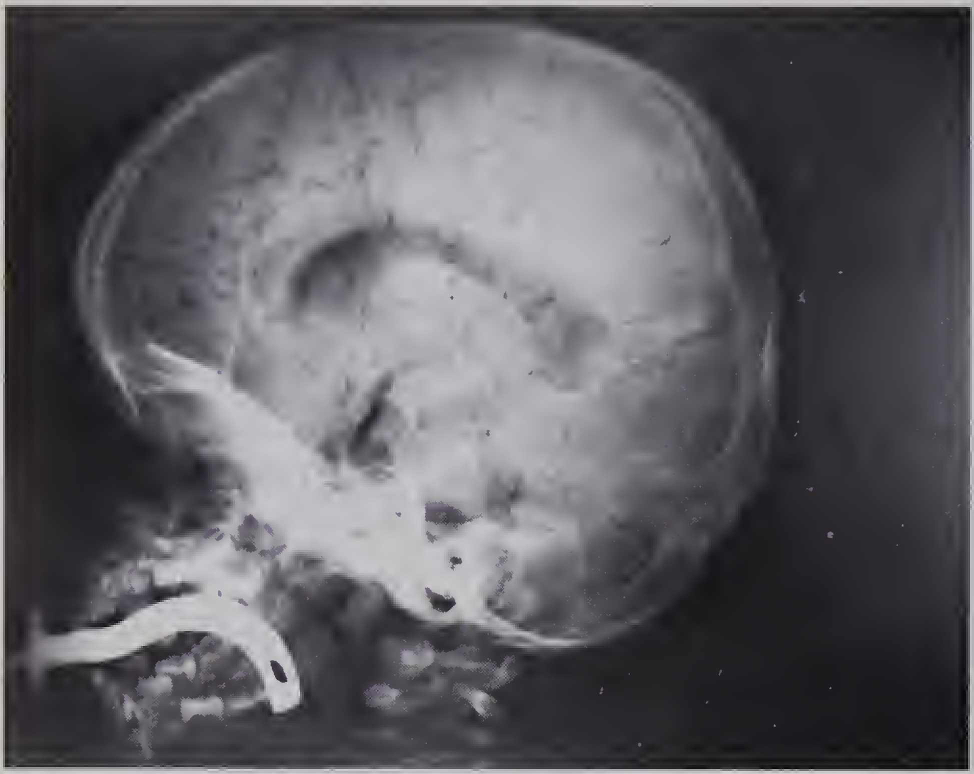
The cerebellum functions further in strengthening impulses to the muscles. This action is a little like picking up a weak radio or television signal and amplifying it before broadcasting it.



44-3 These are the control areas of the cerebrum. Notice that some are for the origin of action and some for the termination, or interpretation, of senses.

Another function of the cerebellum is maintenance of tone in muscles. The cerebellum cannot originate a muscular contraction, but it can cause the muscles to remain in a state of partial contraction. You are not aware of this because the cerebellum operates below the level of consciousness.

The cerebellum functions also in maintaining balance. In this activity it is assisted by impulses from the eyes and from the organs of equilibrium of the inner ears. Impulses from both of these organs inform the cerebellum of your position in relation to your surroundings. The cerebellum in turn maintains contractions of the muscles necessary to balance your body.



44-4 In this "air" X-ray photograph of the brain, the cerebrospinal fluid has been drained through the spine and replaced by air. Since the patient was under an anesthetic, the white "airway" was placed in the mouth to avoid having the tongue fall back and cut off the air supply. (Indiana University Medical Center)

The brain stem. Nerve fibers from the cerebrum and cerebellum enter the brain stem, an enlargement at the base of the brain. The lowest portion of the stem, the ***medulla oblongata,*** is located at the base of the skull and protrudes from the skull slightly where it joins the spinal cord. Another part of the brain stem is the ***pons*** (ponz), which receives stimuli from the facial area.

There are twelve pairs of ***cranial nerves*** connected to the brain. These are part of the peripheral nervous system and act as direct connections with certain important organs of the body. One pair, for example, connects the eyes with the brain. Another cranial nerve connects the brain with the lungs, heart, and abdominal organs.

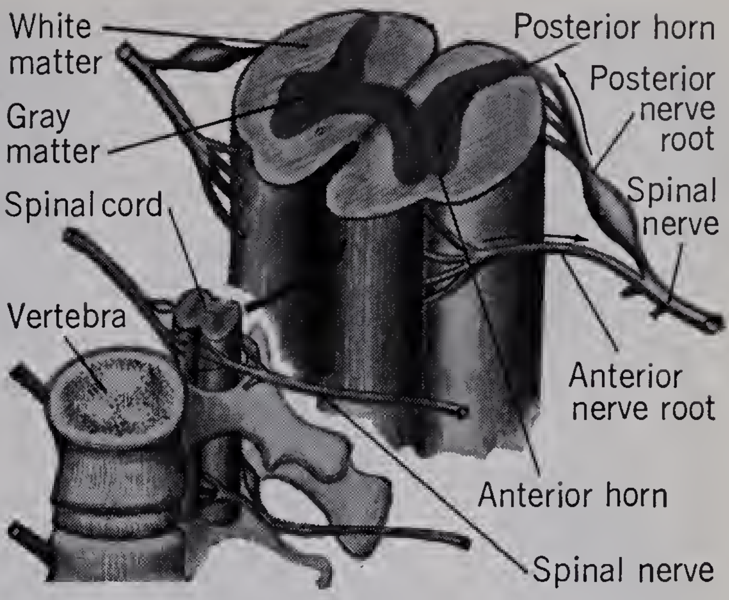
The medulla oblongata controls the activity of the internal organs. The respiratory control center we discussed in the last chapter is located here. Heart action, muscular action of the walls of the digestive organs, secretion in the glands, and other automatic activities are also controlled by the medulla oblongata.

The spinal cord and spinal nerves. The ***spinal cord*** extends from the medulla oblongata through the protective bony arch of each vertebra, almost the length of the spine. Its outer region is white matter, made up of great numbers of nerve fibers covered by sheaths. Neurons, composing the gray matter, lie inside the white matter in a form similar to the shape of a butterfly with its wings spread (Fig. 44–5). The pointed tips of the wings of gray matter are called *horns.* The *posterior* pair points toward the back of the cord while the *anterior* pair points toward the front of the cord.

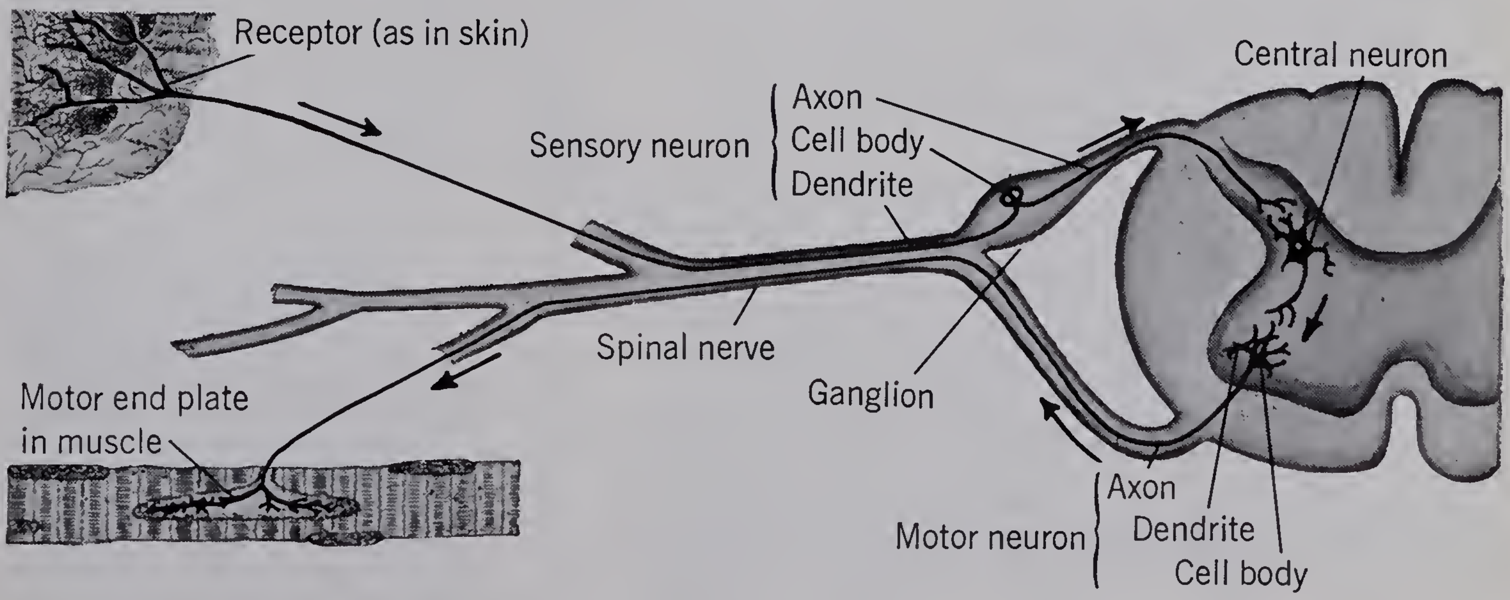
Thirty-one pairs of ***spinal nerves*** branch off the cord between the bones of the spine. Along with the cranial nerves, these nerves and their branches form the peripheral nervous system. One of a pair goes to the right side of the body. Its mate goes to the left side. Spinal nerve branches begin in the neck and continue the full length of the cord. These large cables are mixed nerves. Some of their many fibers are sensory and carry impulses into the spinal cord, while others are motor and lead impulses away from it. Each spinal nerve divides just outside the cord. The sensory fibers that carry impulses from the body into the spinal cord branch to the posterior horns of the gray matter. This branch of each spinal nerve has a *ganglion* (near its point of entry to the cord), in which the sensory cell bodies are found. The other branch at the junction leads from the anterior horns of the spinal cord, in which the motor cell bodies are located. The motor fibers of this branch carry impulses from the spinal cord to the body.

If the spinal cord were cut, all parts of the body controlled by nerves below the point of severance would be totally paralyzed. Such an injury might be compared to cutting the main cable to a telephone exchange.

Nervous reactions. Nervous reactions vary greatly in form and complexity. The simplest of these is the ***reflex action*** (Fig. 44–6). It is an automatic reaction involving the spinal cord or the brain. The knee jerk is an excellent example of a simple reflex action. If you allow your leg to swing freely and strike the area just below the kneecap with a narrow object, the foot jerks upward. This reaction is entirely automatic. Striking the knee stimulates a sensory neuron in the lower leg. An impulse travels along the dendrite to the spinal cord. Here the impulse travels to a central neuron. This neuron in turn stimulates a motor neuron extending to the leg muscles, causing a jerk. The entire reflex takes only a split second.


White matter
Gray matter
Spinal cord
Vertebra
Posterior horn
Posterior nerve root
Spinal nerve
Anterior nerve root
Anterior horn
Spinal nerve

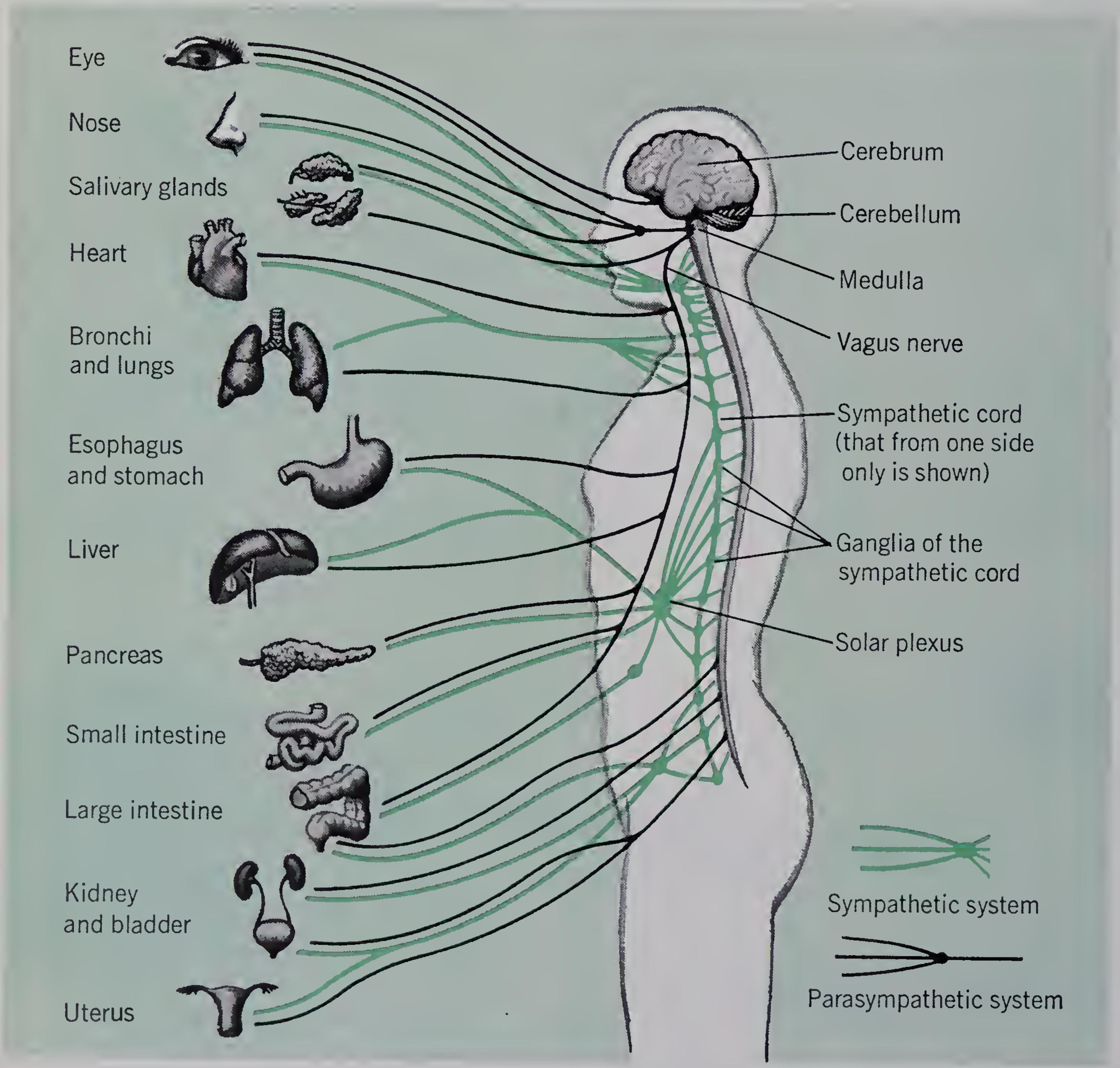
44-5 This drawing shows in cross-section the structures of the spinal cord. Notice that, unlike in the brain, the outer region is the white matter. What do you think the small arrows indicate?


Receptor (as in skin)
Sensory neuron
Axon
Cell body
Dendrite
Central neuron
Spinal nerve
Ganglion
Motor end plate in muscle
Motor neuron
Axon
Dendrite
Cell body

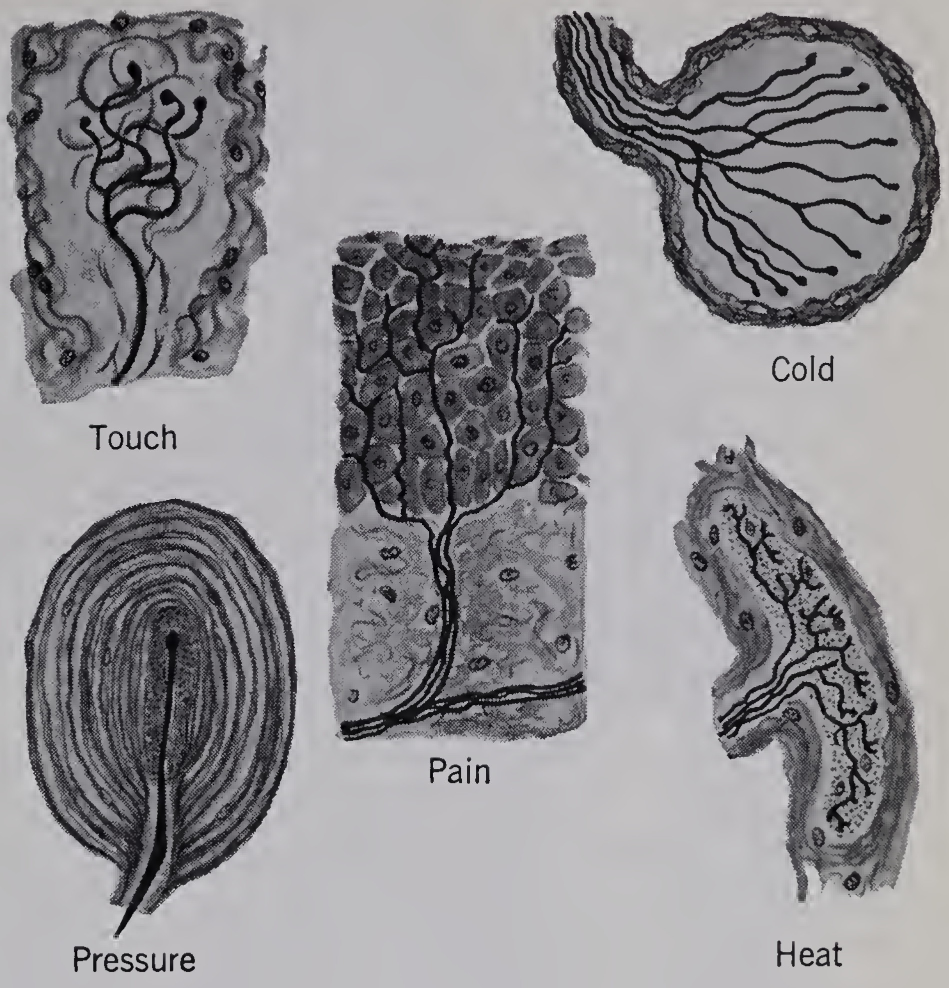
44-6 Trace the path of this impulse from the stimulus to the response. Why are reflex actions said to be automatic?

When you touch a hot object, you experience a similar reflex. Your hand jerks away almost instantly. After the reflex is completed, the impulse reaches the brain and registers pain. However, if the muscle response had been delayed until the pain impulse had reached the brain and a motor impulse traveled down the spinal cord from the cerebral motor area, the burn injury would have been much greater. Other reflex actions include sneezing, coughing, blinking the eyes when the cornea is touched, laughing when tickled, and jumping when frightened.

The autonomic nervous system. The autonomic nervous system is entirely involuntary and automatic. It is composed of two parts, one of which is called the ***sympathetic system.*** This system includes two rows of nerve tissue, or cords, which lie on either side of the spinal column. Each cord has ganglia, which contain the bodies of neurons. The largest of the sympathetic ganglia is the *solar plexus,* located just


Eye
Nose
Salivary glands
Heart
Bronchi and lungs
Esophagus and stomach
Liver
Pancreas
Small intestine
Large intestine
Kidney and bladder
Uterus
Cerebrum
Cerebellum
Medulla
Vagus nerve
Sympathetic cord (that from one side only is shown)
Ganglia of the sympathetic cord
Solar plexus
Sympathetic system
Parasympathetic system

44-7 The autonomic nervous system regulates the internal organs of the body. What are the functions of its two divisions?



44-8 The five types of receptors found in the skin. The nerve fibers are drawn in solid black; the accompanying structures in gray.

below the diaphragm. Another is near the heart; a third is in the lower part of the abdomen; and a fourth is in the neck. Fibers from the sympathetic nerve cords enter the spinal cord and connect with it and with the brain, as well as with one another. The sympathetic nervous system helps to regulate heart action, the secretion of ductless glands, blood supply in the arteries, the action of smooth muscles of the stomach and intestine, and the activity of other internal organs.

The *parasympathetic system* opposes the sympathetic system and thus maintains a system of check and balance. The principal nerve of the parasympathetic system is the *vagus nerve,* a cranial nerve that extends from the medulla oblongata, through the neck, to the chest and abdomen. The check-and-balance system is illustrated by the fact that the sympathetic system speeds up heart action, while the vagus nerve slows it down.

The sensations of the skin. The skin has five different types of nerve endings, each associated with a different sensation. The nerve endings in the skin are terminal branches of dendrites of sensory neurons and are called ***receptors.*** Some receptors are many-celled; some consist of only one specialized cell; and some are the bare nerve endings themselves. Each receptor is suited to receive only one type of stimulus and to start impulses to the central nervous system. The skin has five different types of receptors. Certain of these respond to touch, while others receive stimuli of pressure, pain, heat, or cold (Fig. 44–8).

Normally no one receptor reacts to more than one stimulus, and thus the five sensations of the skin are distinct and different. The *pain* receptor, for example, is a bare dendrite. If the stimulus is strong enough, a pain receptor will react to mechanical, thermal, electrical, or chemical stimuli. The sensation of pain is a protective device used to signal a threat of injury to the body. Pain receptors are distributed through the skin.

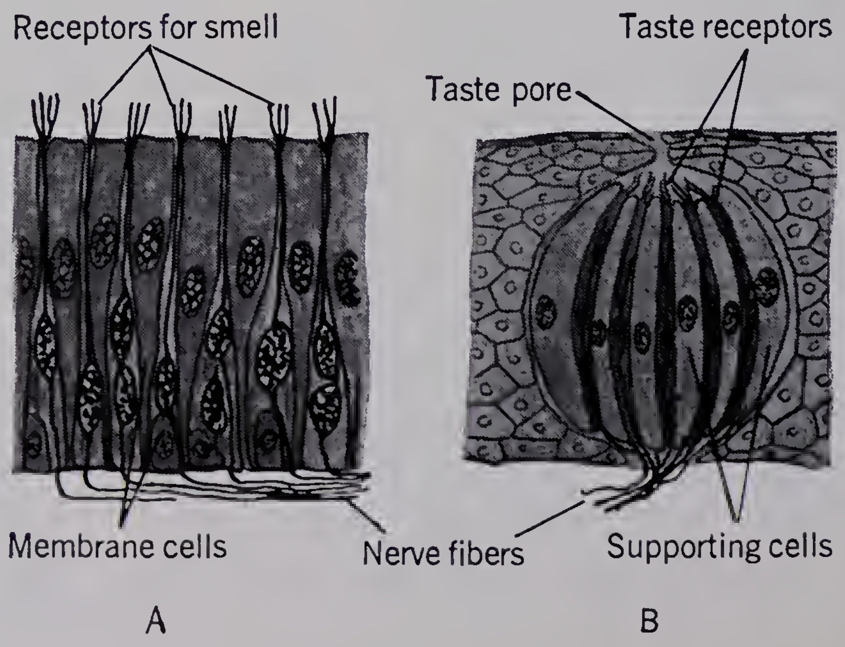
The sensory nerves of the skin are distributed unevenly over the skin area in spots and lie at different depths in the skin. For instance, if you move the point of your pencil over your skin very lightly, you stimulate only the nerves of *touch*. These nerve endings are close to the surface of the skin in the region of the hair sockets. The fingertips, the forehead, and the tip of the tongue contain abundant nerve endings that respond to touch.

Nerve endings that respond to *pressure* lie deeper in the skin. If you press the pencil point against the skin, you feel pressure in addition to touch. Since the nerves are deeper, a pressure stimulus must be stronger than a touch stimulus. You may think that there is no difference between touch and pressure. But the fact that you can distinguish the mere touching of an object from a firm grip on it indicates that separate nerves are involved.

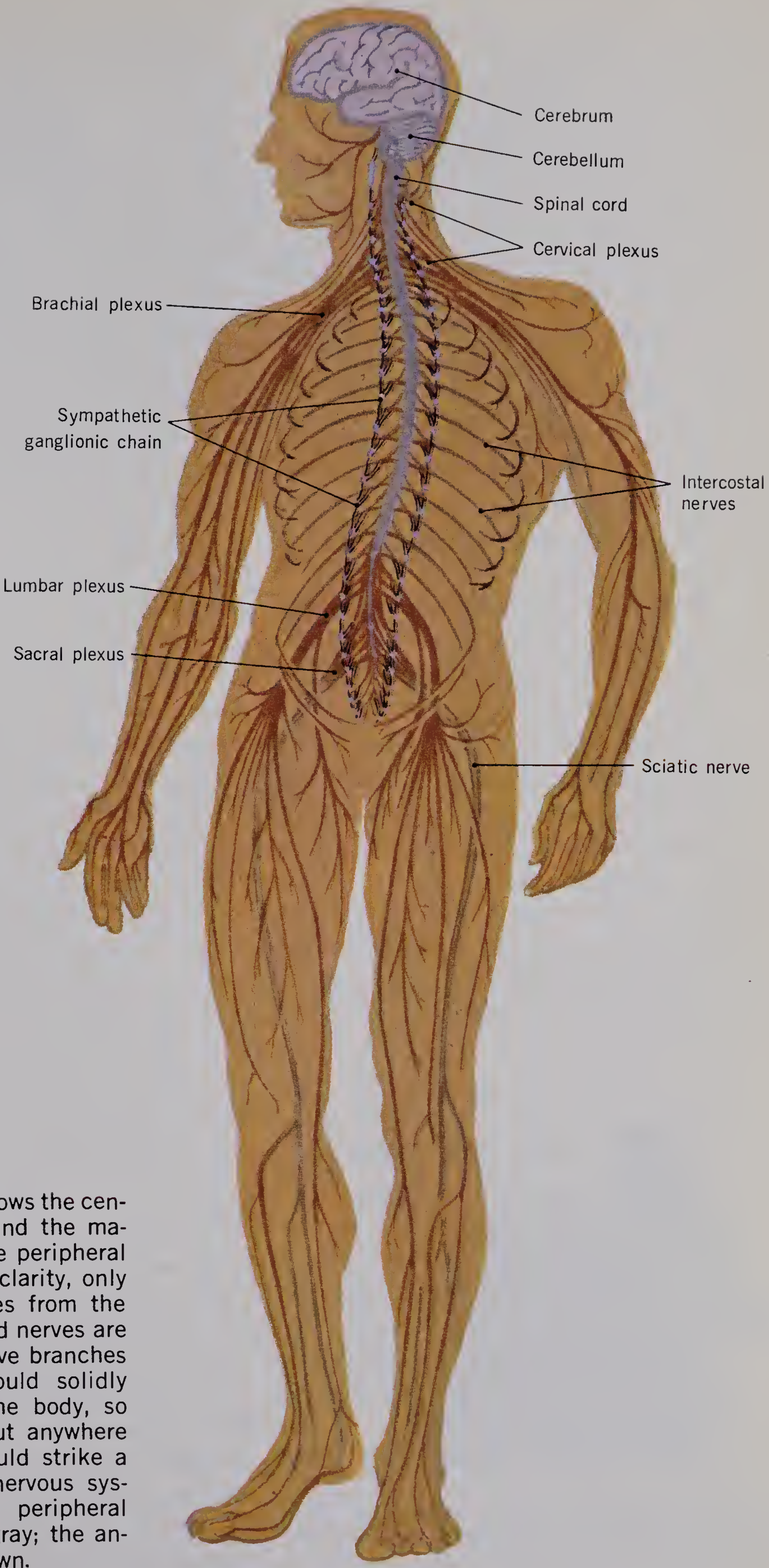
Heat and *cold* stimulate separate nerve endings, which is an interesting protective device of the body. Actually cold is not an active condition. Cold results from a reduction in heat energy. If temperature stimulated a single nerve, impulses would be strong in the presence of great heat and would become weaker as heat decreased. There would be no impulses in greatly reduced heat (intense cold). However, since some nerves are stimulated by heat and others by the absence of it, we are constantly aware of both conditions.

The sense of taste. Taste results from the chemical stimulation of certain nerve endings. Since nearly all animals prefer some food substances to others, we must assume that they can distinguish different chemical substances. The sense of taste in man is centered in the ***taste buds*** of the tongue. These flask-shaped structures, containing groups of nerve endings, lie in the front area of the tongue, along its sides, and near the back. Foods, mixed with saliva and mucus, enter the pores of the taste buds and stimulate the hairlike nerve endings (Fig. 44-9).

Our sense of taste is poorly developed. We recognize only four common flavors: *sour, sweet, salty,* and *bitter.* Taste buds are distributed unevenly over the surface of the tongue.



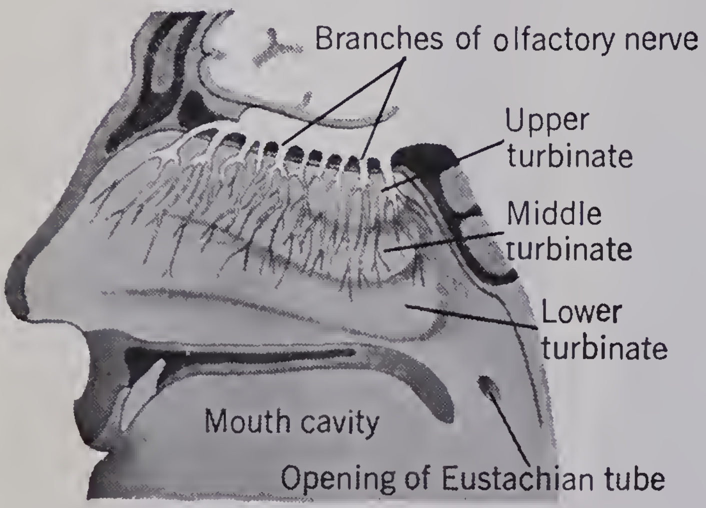
44-9 Diagram A shows how a section of the membrane of the nose would appear under a microscope. Diagram B shows a section of the tongue through a taste bud.


Cerebrum
Cerebellum
Spinal cord
Cervical plexus
Brachial plexus
Sympathetic ganglionic chain
Intercostal nerves
Lumbar plexus
Sacral plexus
Sciatic nerve

44-10 This diagram shows the central nervous system and the major nerve trunks of the peripheral nervous system. For clarity, only a few of the branches from the major nerve trunks and nerves are shown. If all the nerve branches were shown, they would solidly fill this outline of the body, so that if a pin were put anywhere on this outline it would strike a nerve. The central nervous system and posterior peripheral nerves are drawn in gray; the anterior ones are in brown.

Those sensitive to sweet flavors are at the tip of the tongue. Doesn't candy taste sweeter when you lick it than when you chew it far back in the mouth? The tip of the tongue is also sensitive to salty flavors. You taste sour substances along the sides of the tongue. Bitter flavors are detected on the back of the tongue, which explains why a bitter substance does not taste bitter at first. If a substance is both bitter and sweet, you sense the sweetness first, then the bitterness. Substances such as pepper and some other spices have no distinct flavor, but irritate the entire tongue and produce a burning sensation.

Much of the sensation we call taste is really smell. When you chew foods, vapors enter the inner openings of the nose and reach nerve endings of smell. If the external nasal openings are plugged up, many foods lack the flavor we associate with them. Under such conditions onions and apples have an almost identical sweet flavor. You probably have noticed the loss of what you thought was taste sensation when you had a head cold and temporarily lost your sense of smell.



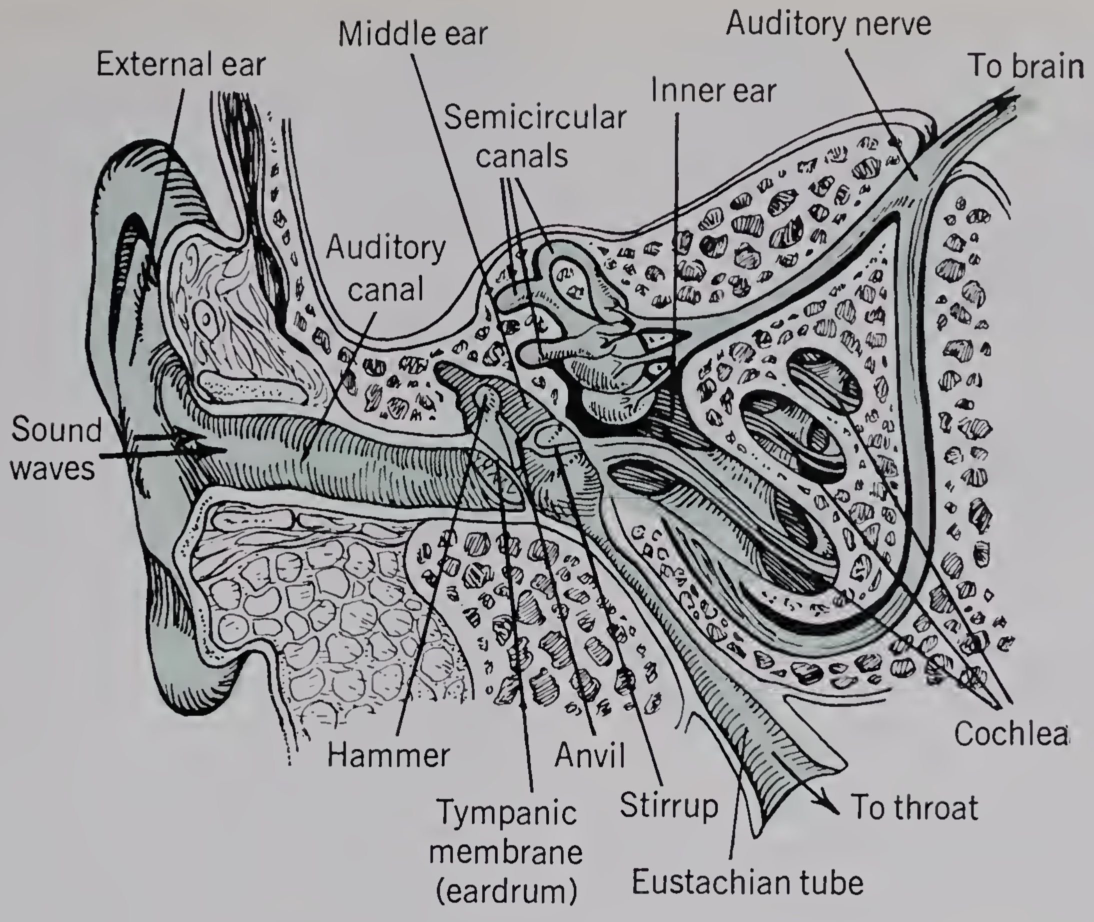
44-11 Here you see the surface of the inner wall of the nose. What function does the Eustachian tube perform?

The sense of smell. Like taste, smell results from the chemical stimulation of nerves, except that odors are in the form of gases. The nasal passages are arranged in three tiers, or layers, of cavities, separated by bony layers called ***turbinates.*** The upper turbinate contains branched endings of the ***olfactory nerve,*** which is a cranial nerve (Fig. 44–11). Stimulation of these endings by odors results in the sensation of smell. Receptors that are exposed to a particular odor over a long period of time become deadened to it, although they are receptive to other odors. Nurses are not usually aware of the odor of iodoform in a hospital, but a visitor is.

The structure of the human ear. Our ears and those of other mammals are wonderfully complex organs. The external ear opens into an ***auditory canal*** embedded in the skull (Fig. 44–12). The canal is closed at its inner end by the ***eardrum,*** or *tympanic membrane,* which separates it from the middle ear. The middle ear connects with the throat through the ***Eustachian*** (yoo-*stay*-shun) ***tube.*** This connection equalizes the pressure in the middle ear with that of the atmosphere.

When the connection between the middle ear and throat is blocked by a cold that involves the Eustachian tube, the pressures outside and inside do not equalize. For this reason divers and fliers do not work when they have a cold. The outside pressure increases during a dive. But with a blocked Eustachian tube, the middle-ear pressure would not be equalized and the difference might burst the eardrum. The flier's situation would, of course, be the reverse, in that the pressure would be less outside than in the middle ear.

Three tiny bones, the ***hammer,*** ***anvil,*** and ***stirrup,*** form a chain across



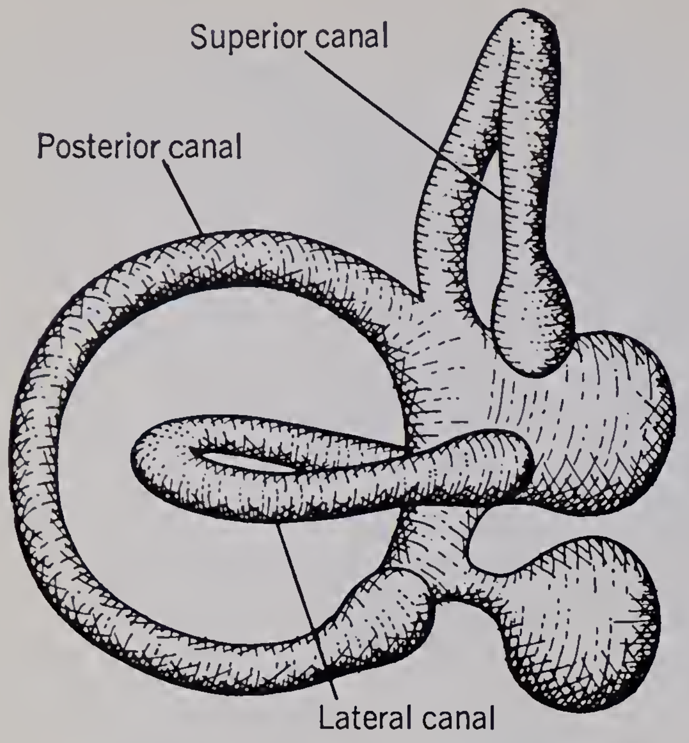
44-12 The structure of the human ear.

the middle ear. They extend from the inner face of the eardrum to a similar membrane that covers the ***oval window,*** which is the opening to the inner ear.

The inner ear is composed of two general parts. The ***cochlea*** (*kahk*-lee-a) is a spiral passage resembling a snail shell. It is filled with a liquid and is lined with nerve endings that receive the sound impressions. The ***auditory nerve*** leads from the cochlea to the brain. The ***semicircular canals*** consist of three loop-shaped tubes, each at right angles to the other.

How we hear. An object vibrating in air produces regions in which the air molecules are squeezed together (compressions) and regions in which they are farther apart (rarefactions). This regular pattern produced by any vibrating object in air or other matter is called a sound wave. When sound waves reach the ear, they pass through the external ear into the auditory canal and to the eardrum. Here they cause the eardrum to vibrate in time with the compressions and rarefactions of the sound wave. The vibration of the eardrum in turn causes the hammer, anvil, and stirrup bones of the middle ear to vibrate. The vibration is transmitted to the membrane of the inner ear and sets the fluid in the cochlea in motion. Vibration of the fluid in turn stimulates the nerve endings in the cochlea. Impulses travel through the auditory nerve to the cerebrum, where the sensation of sound is perceived. If the auditory region of the cerebrum ceases to function, a person cannot hear, even though his ear mechanisms receive vibrations normally.

The sense of balance. Our sense of equilibrium, or balance, is centered in the semicircular canals (Fig. 44–13) of the inner ears. These canals lie at right angles to one another in three different planes. Their position has been compared to the parts of a chair. One canal lies in the plane of the seat, an-



44-13 The semicircular canals in the inner ear function in maintaining balance. Notice that each canal is at right angles to the other two.

other in the plane of the back, and a third in the plane of the arms.

The semicircular canals contain a great number of receptors and a fluid similar to that of the cochlea. When the head changes position the fluid rocks in the canals and stimulates these receptors. Impulses travel from them through a branch of the cerebellum. Thus the brain is made aware of the position of the head. Since the canals lie in three planes, any change in position of the head moves the fluid in one or more of them. If you spin around rapidly, the fluid is forced to one end and impulses travel to the brain. When you stop spinning, the fluid rushes back the other way, giving you the sensation of twirling in the opposite direction, so that you feel dizzy. Regular rhythmic motions produce unpleasant sensations that involve the whole body. These sensations are what we call *motion sickness.* Disease of the semicircular canals results in temporary or permanent dizziness and loss of equilibrium.

The structure of the human eye. The normal eye is spherical and slightly flattened from front to back (Fig. 44–14). The wall of the eyeball is composed of three distinct layers. The outer, ***sclerotic layer*** (skle-*raht*-ik) is tough and white. This layer shows as the white of the eye. It bulges and becomes transparent in front, and is called the ***cornea.***

The middle, ***choroid layer*** is richly supplied with blood vessels. It completely encloses the eye except in front where there is a hole. This small opening, lying behind the center of the cornea, is the ***pupil.*** Around the pupil the choroid contains pigmented cells. This area is the ***iris*** and may be colored blue, brown, hazel, or green. Change in size of the circular pupil is accomplished by muscles in the iris. This adjustment in size of the pupil opening to the intensity of light is an automatic reflex. When the light is reduced, the pupil becomes large, or dilates. In bright light it constricts, or becomes small. The eye doctor uses drops to block the automatic iris reflex so that he can use a bright pinpoint of light to see inside the eye. This is the only place in the body where the blood vessels may actually be seen. The black pigment of the choroid layer may also be seen inside the eye. This black pigmentation prevents reflection of light rays within the eye.

A convex, ***crystalline lens*** lies behind the pupil opening of the iris. The lens is supported by the ***ciliary muscles*** fastened to the choroid layer. Contraction of these muscles changes the shape of the lens. In this way varying light rays are focused on the surface of the retina in the eye.

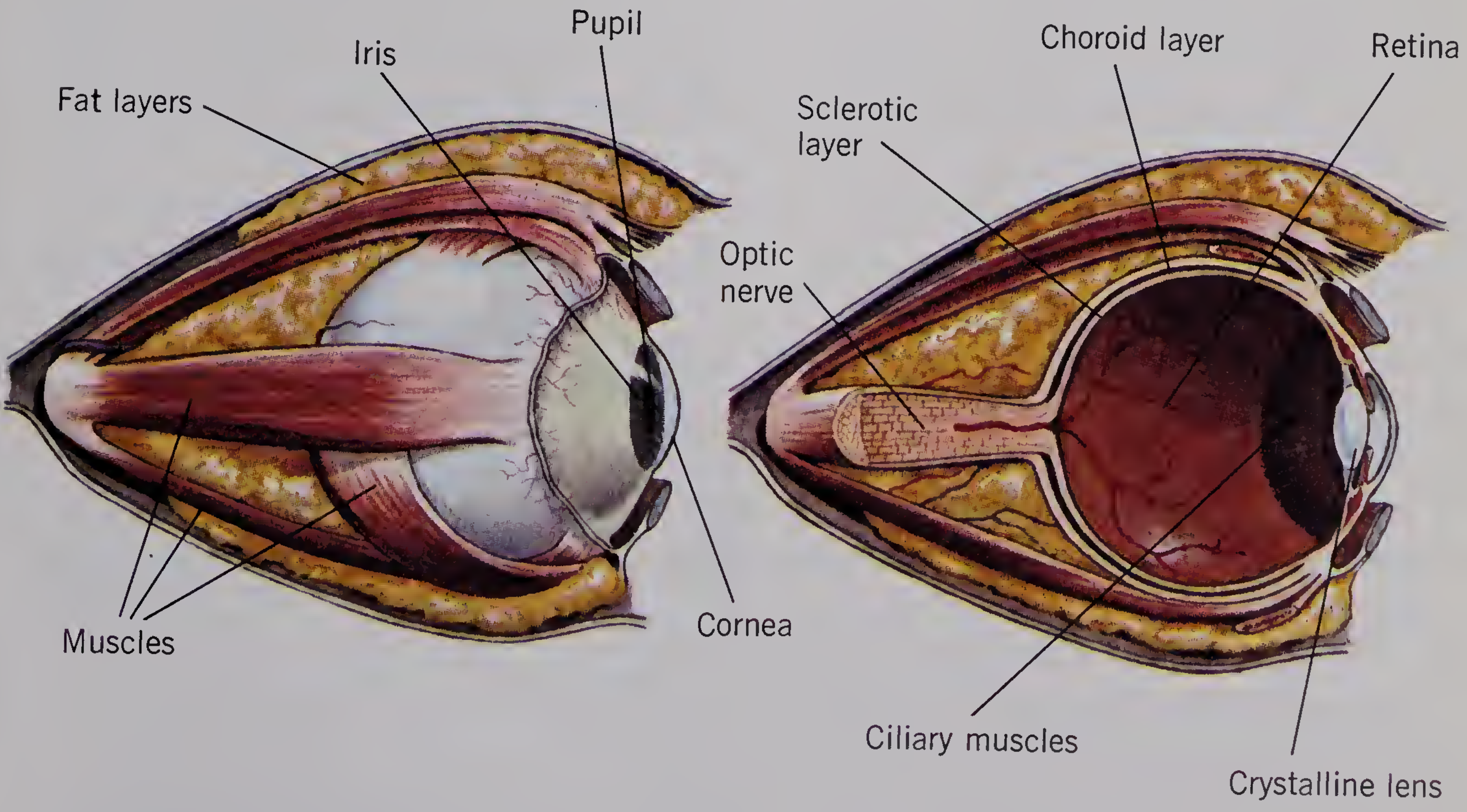
The space between the lens and the

cornea is filled with a thin, watery substance, the ***aqueous humor.*** A thicker, jellylike transparent substance, the ***vitreous humor,*** fills the interior of the eyeball. This fluid aids in keeping the eyeball firm and preventing its collapse.

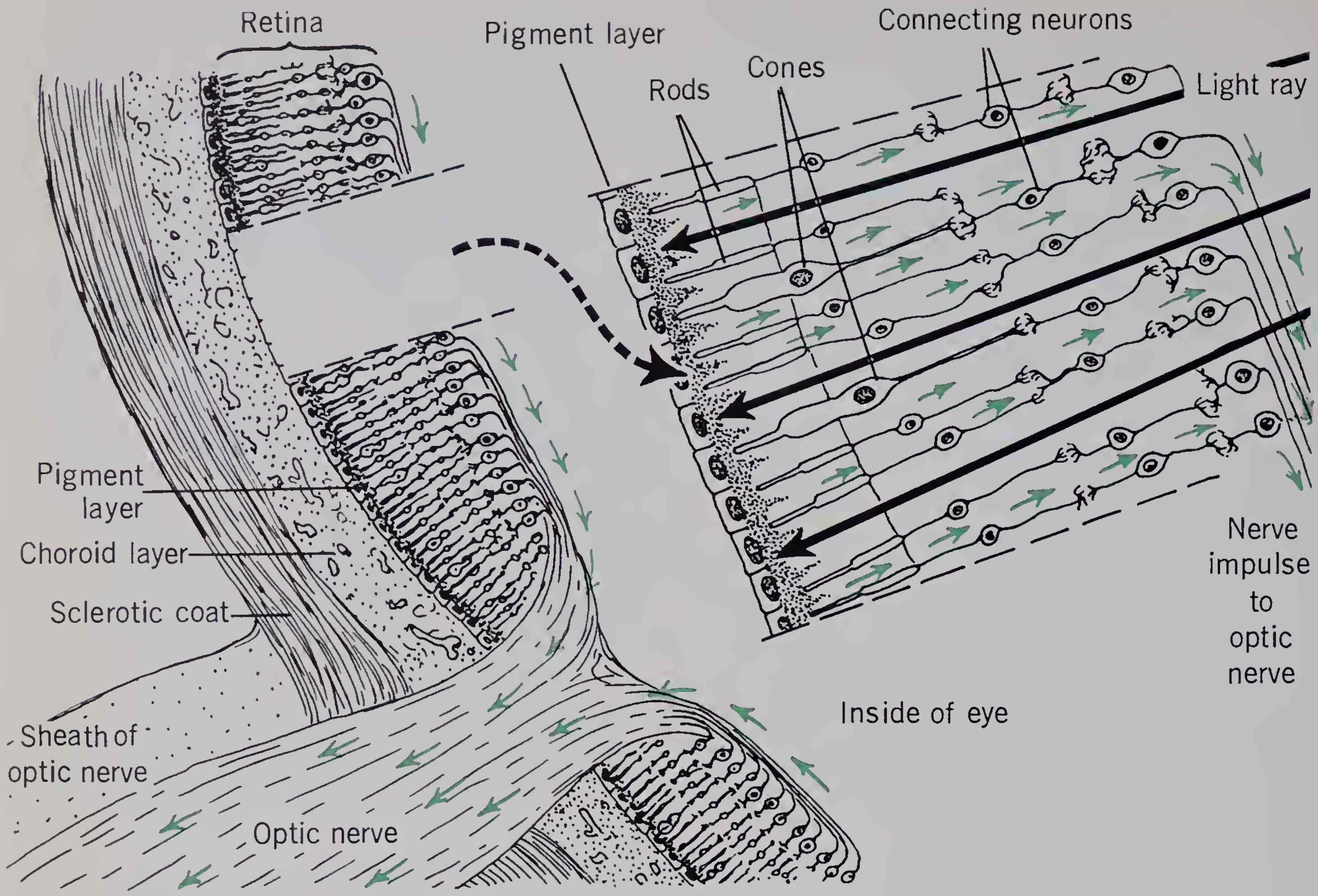
The inner layer, or ***retina,*** is the most complicated and delicate of the eye layers. The terminals of the ***optic nerve,*** a cranial nerve, are found in the retina. This large nerve extends from the back of each eyeball to the vision center in the occipital lobe of the cerebrum. Some of the fibers cross as they lead to the cerebrum. This means that some of the impulses from your right eye, for example, go to the left occipital lobe and some go to the right occipital lobe. Thus, what you see with each eye is interpreted in both lobes.

Eye movement and protection. The eye rests in its socket against layers of fat which serve as cushions. Movements of the eyeball are accomplished by pairs of muscles which attach to its sides and extend back into the eye socket (Fig. 44–14, left). The sclerotic layer is supplied with nerve endings that register pain when a foreign object touches it. The eye is further protected by its location deep in the recesses of the eye socket, by bony ridges, by the eyelids, and by the tear glands that keep its surface moist. Tears wash over the eye and drain into the tear ducts in the lower corner of the eye socket, which leads to the nasal cavity. Because tears contain an antibacterial enzyme, they are mildly antiseptic.

The structure of the retina. The retina is less than 1/80th of an inch thick. Yet it is composed of seven layers of cells, receptors, ganglia, and nerve fibers. The function of all the structures of the eye is to focus light on the retina. The specialized receptors that are stimulated by light are called *photoreceptors* and are of two types, cones and rods (Fig. 44–15). ***Cones*** are sensitive to bright light and are responsible for color vision. The ***rods*** act in reduced light but do not respond to color. Perhaps the phrase



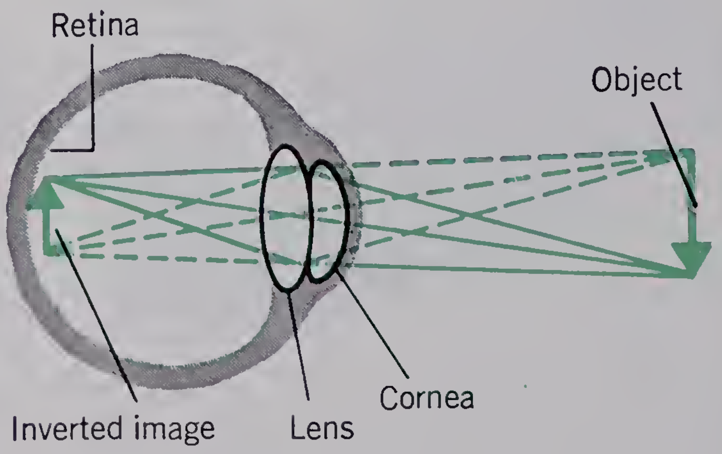
44-14 Left: a view of the human eye showing the muscles and socket. Right: a cutaway diagram showing the various internal structures.


Retina
Pigment layer
Connecting neurons
Cones
Rods
Light ray
Pigment layer
Choroid layer
Sclerotic coat
Sheath of optic nerve
Optic nerve
Nerve impulse to optic nerve
Inside of eye

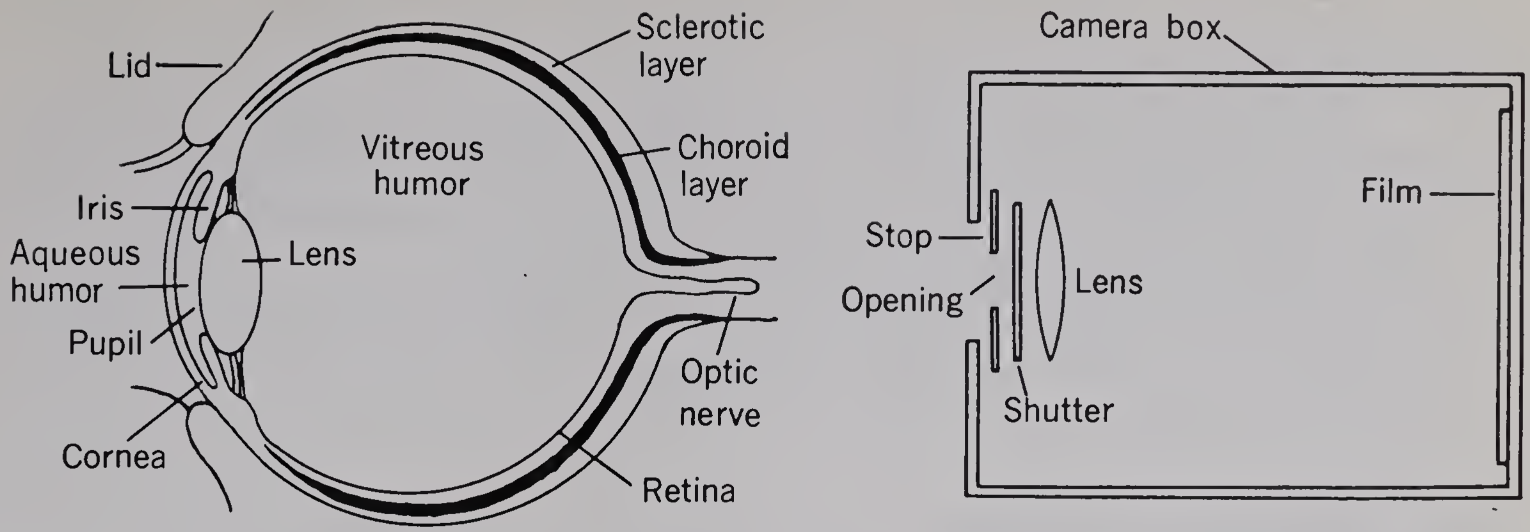
44-15 This drawing shows the structures at the back of the eye. The enlargement on the right illustrates the arrangements of the rods and cones of the retina.

"cones color, rods reduced" will help you to keep the two straight. They lie deep in the retina, pointing toward the back surface of the eyeball. Impulses from the cones and rods travel through a series of short nerves with brushlike endings to ganglia near the front part of the retina. More than half a million nerve fibers lead from the ganglia over the surface of the retina to the optic nerve. There are no rods or cones at the point where the end of the optic nerve joins the retina. Since there is no vision at this point, it is called the *blind spot.*

How we see. Cones occur throughout the retina, but are especially abundant in a small, sensitive spot called the *fovea* (foh-*vee*-a). When we see in daylight, light rays pass through the cornea, aqueous humor, pupil, lens, and the vitreous humor to the cones of the retina. The lens focuses rays on the fovea, the point at which we see an object clearly. As light rays pass through the lens, they cross and strike the retina in an inverted position (Fig. 44-16). Cones outside the fovea register vision only indistinctly. Thus, if you focus


Retina
Object
Inverted image
Lens
Cornea

44-16 How we see. Light rays enter the eye, cross in the lens, and focus on the retina. Why is the image inverted on the retina?



44-17 Study these two drawings, which represent parts of the human eye and those of a camera. Then, indicate exactly how the parts of the camera are similar to those of the eye and how these parts differ.

your eyes on an object, you see it clearly. In addition, you see indistinctly objects contained in a hemisphere of vision, or "out of the corner of your eye."

During the late evening or at night, the light is too reduced to stimulate the cones. This quality of light stimulates the rods. Rods produce a substance we call ***visual purple***, which is necessary for their proper functioning. Bright light fades visual purple, which causes the rods to be insensitive to further stimulation by light. This explains why, when you leave a bright room at night, you are temporarily night blind. As visual purple is restored, the rods begin to function, and you can see objects in dim light.

The human eye contains fewer rods than many animal eyes, so that our night vision is relatively poor. The cat, deer, and owl see well at night because they have many rods. The owl, however, lacks cones and is day blind.

The fovea of your retina contains many cones but no rods. This explains why you can see an object "out of the corner of your eye" at night, but when you focus on it, it disappears.

IN CONCLUSION

The brain and spinal cord compose the central nervous system. They communicate with all parts of the body by nerves. The cerebrum controls conscious activities. It is the center of intelligence and contains both sensory and motor areas. Impulses from the cerebral motor area pass through the cerebellum, where coordination of impulses takes place. The medulla oblongata controls the activity of internal organs and is the control center of respiration.

Sensory nerves carry impulses from their receptors in sense organs to the central nervous system. The numerous minute sense organs of the skin respond to touch, pressure, pain, heat, and cold. The endings involved in the sense of smell contact odors that have reached the upper turbinate region of the nasal passages. The ears are highly developed sense organs which receive air-borne vibrations and carry them to the receptors in the cochlea in the inner ear. They also contain the semicircular canals, which control our sense of equilibrium.

The eye is the most highly specialized of the sense organs. It receives light rays through the pupil and directs them to the retina by means of the lens. In the retina, the photoreceptors send impulses through the optic nerve to the visual center in the occipital lobes of the brain.

In the next chapter we shall see how the nervous system and sense organs are affected by alcohol, narcotics, and tobacco.

BIOLOGICALLY SPEAKING

anvil bone
aqueous humor
auditory canal
auditory nerve
autonomic nervous system
axon
central nervous system
central neurons
cerebellum
cerebrospinal fluid
cerebrum
choroid layer
ciliary muscles
cochlea
cone
cornea
cranial nerves
crystalline lens
dendrite
eardrum
Eustachian tube
fovea
hammer bone
iris
medulla oblongata
meninges
motor neuron
nerve
nerve impulse
neuron
olfactory nerve
optic nerve
oval window
parasympathetic nervous system
peripheral nervous system
pons
pupil
receptor
reflex action
retina
rod
sclerotic layer
semicircular canals
sensory neuron
spinal cord
spinal nerve
stirrup bone
sympathetic nervous system
synapse
taste buds
turbinate
visual purple
vitreous humor

QUESTIONS FOR REVIEW

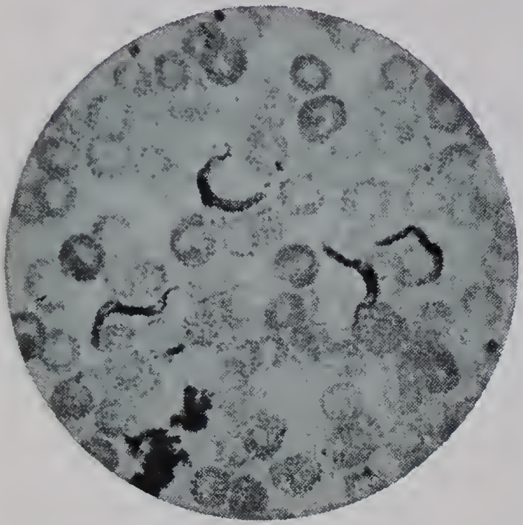
1. Name the three main divisions of the nervous system and state the functions of each.
2. Why are peripheral nerves containing only axons considered to be motor nerves?
3. What occurs at the endings of a motor neuron that causes a muscle fiber to contract? What causes it to relax?
4. Name the parts of the brain and state the functions of each.
5. In what way is the autonomic nervous system really two systems?
6. Name the five sensations of the skin. In what ways are the receptors different?

7. Account for the fact that we think we distinguish more than the five tastes the tongue can perceive.
8. Describe how a sound wave in the air is able to stimulate the receptors in the cochlea.
9. How can an infection in the middle ear produce temporary deafness?
10. Describe the movements of the head that would be necessary to stimulate each semicircular canal separately.
11. Why is our vision at night relatively poor when compared to the eyes of an owl?
12. Why is it that you can see an object out of the corner of your eye at night, but when you focus on it, it disappears?

APPLYING PRINCIPLES AND CONCEPTS

1. What is intelligence?
2. Explain the activity that occurs after a chicken has had its head cut off.
3. Explain the fact that the sympathetic nervous system is sometimes called "the system for fight or flight."
4. How would you go about designing an experiment to prove whether or not the eye really receives an image upside down, while the brain interprets it oppositely?

CHAPTER 45



ALCOHOL, NARCOTICS, AND TOBACCO

Three social and health problems. Problems resulting from alcohol and narcotics are as old as civilization. But they are more acute today because automobiles, firearms, and other mechanical devices become implements of destruction in the hands of an intoxicated or drug-addicted person.

We shall consider alcohol, tobacco, and narcotics together, because they are all harmful substances when used habitually. Young people who see a large proportion of adult society smoking without any *apparent* effect may arrive at the wrong conclusions, because the long-term effects of tobacco are not always visible. While there is no real justification for the use of tobacco, its influence on the human mechanism is not to be compared with the social, emotional, and mental damage resulting from the habitual and excessive use of alcohol or narcotics. This chapter will show you some of the effects of these substances on the body. It will be up to each of you, as an individual, to form your own opinion and your own personal habits.

Alcohol in the body. Alcohol does not have to be changed in form or composition in the stomach before absorption occurs. It starts to enter the blood within two minutes and is rapidly absorbed and delivered to the tissues. This absorption is even more rapid when the stomach is empty than when it contains food.

Oxidation in the tissues begins immediately, and large amounts of heat are released. The body tissues oxidize alcohol at the rate of approximately one ounce in three hours. Because this rate cannot be changed according to the energy needs of the body, alcohol has no value as a food. The excess heat is picked up by the blood and delivered to the skin, where it causes the characteristic alcoholic flush. Since the receptors of heat are in the skin, the rush of blood to the skin gives a false impression of warmth. Actually the internal organs are being deprived of adequate blood supply and become chilled.

Some effects of alcohol on the body organs. Alcohol is absorbed by all the body organs, so that all of them are affected by its presence. But some organs seem to be affected more than others. The oxidation of alcohol produces water, which is excreted in large quantities by the skin during heat elimination. The tissues become dehydrated, and this loss of water concentrates nitrogenous wastes in the kidneys, interfering with normal elimination.

Vitamin-deficiency diseases are common among alcoholics, as they often starve themselves during long periods of excessive drinking. In addition, during these fasts the liver is deprived of its stored food and swells as the carbohydrates are replaced by fats. This condition, known as ***fatty liver***, is found in 75 percent of alcoholics. A more serious degeneration of the liver, called ***cirrhosis*** (si-*roh*-sis), occurs eight times more frequently in alcoholics than in other people.

Another organ frequently affected by excessive alcohol is the stomach. Alcohol causes increase in stomach secretions, which often leads to a painful inflammation of the stomach lining called ***gastritis.***

Effects of alcohol on the nervous system. Alcohol is a ***depressant***, as it has an anesthetic effect on the nervous system. You may have heard it referred to as a stimulant because its anesthetic effect releases inhibitions. It is, however, exactly the opposite of a stimulant.

The first effects of alcohol occur in the cortex of the brain. Loss of judgment, will power, and self-control occur. Cares seem to vanish, and the person becomes gay and lightheaded. Influence on the frontal lobe alters emotional control and may lead to a feeling of great joy, shown by foolish laughter, or to sadness and weeping. As the effects of alcohol progress through the brain tissue, the vision and speech areas of the cerebrum become involved. There is blurred or double vision, lack of ability to judge distance, and slurred speech.

As the cerebellum becomes involved, coordination of the muscles is affected. The victim becomes dizzy when standing, and if he is able to walk at all, he does so with a clumsy, staggering gait.

ACCIDENT TOLL IN ONE YEAR
NEARLY

45-1 Drunkometer tests are given to motorists in an effort to reduce highway injuries and deaths. (Wide World Photos)

In the final stages of drunkenness a person becomes completely helpless. The brain cortex ceases activity, resulting in complete unconsciousness. The skin becomes pale, cold, and clammy. Heart action, digestive action, and respiration slow up and the victim lies near death.

Alcoholism is a disease. Six to seven percent of the adult users of alcohol develop an abnormal, chronic dependence on it. This disease, called ***alcoholism***, may begin with occasional social drinking. As distressing situations and problems arise and life seems temporarily unpleasant, the individual uses alcohol as an escape from reality. The problems remain unsolved, and alcohol is used for a definite purpose — to try to escape from the problems. With loss of judgment and will power, the chances of solving these problems are further reduced. The alcoholic then resorts to solitary drinking for the pure effects of alcohol. The destruction of his personality has begun.

If alcoholism is allowed to progress to an acute condition, serious deterioration of brain tissue may result. This may cause terrifying hallucinations known as ***delirium tremens***, or "D.T.'s." The victim has visions of snakes, rats, and other vermin crawling over his body, and becomes violent with fear. By this time his alcoholism has reached the proportions of alcoholic insanity.

Alcohol is the tool and not the underlying cause of alcoholism. Thus the alcoholic seeking a cure must first find the reason for his problem drinking. Then he must attempt to solve the problem, not resort to alcohol as an escape from it. Sympathetic understanding and the cooperation of his family and friends help greatly in overcoming the problem.

Thirty-four states and the District of Columbia have clinics and hospitals to assist alcoholics in curing their condition. They supply both medical treatment and counseling necessary to deal with the problem. Alcoholics Anonymous is a voluntary organization that has resulted in the recovery of 350,000 alcoholics.

Alcohol and the length of life. Life insurance companies ask applicants about their use of alcohol and drugs,

HOW ALCOHOL AFFECTS A DRIVER

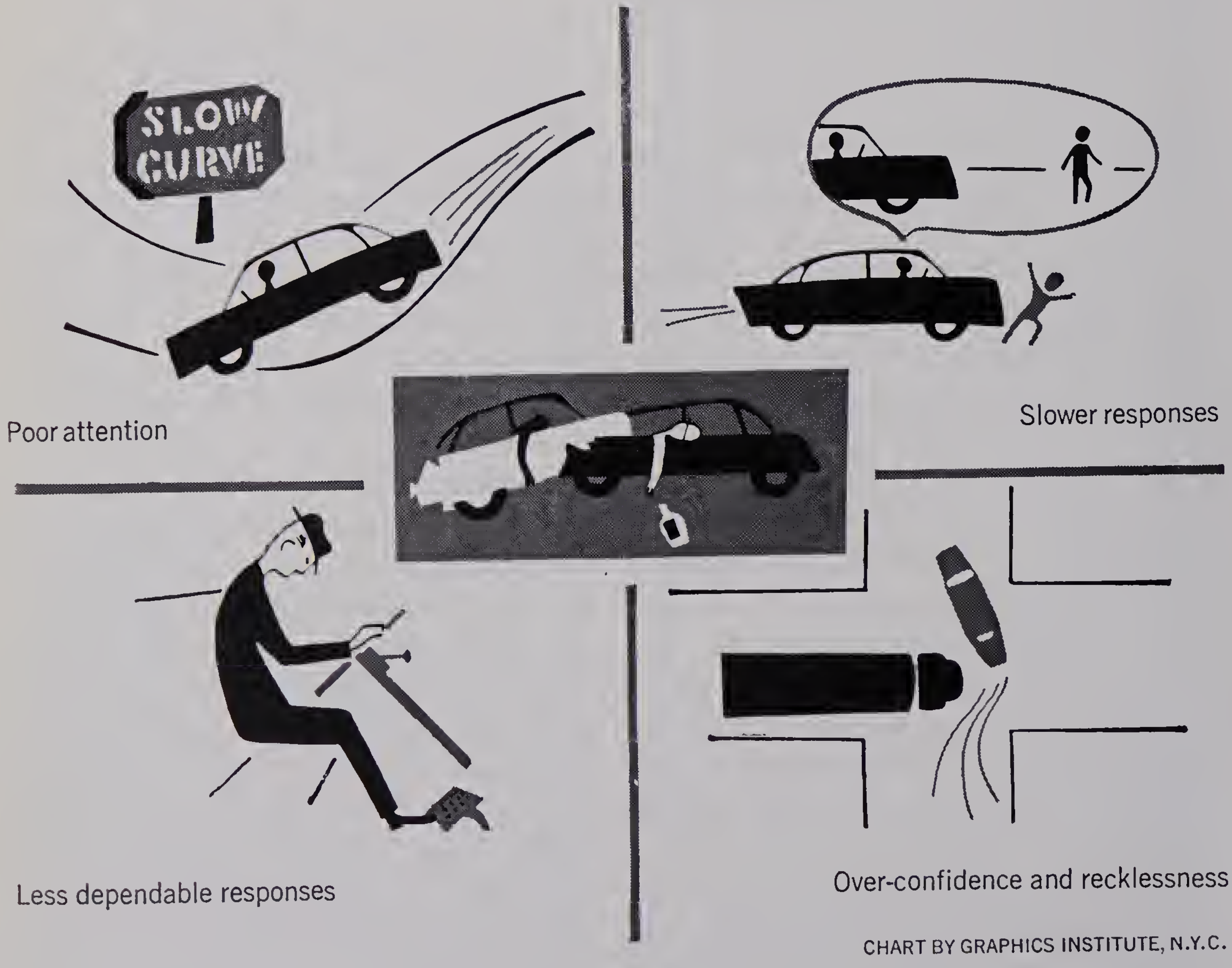


CHART BY GRAPHICS INSTITUTE, N.Y.C.

45-2 Alcohol lowers every aspect of driving efficiency.

which is evidence that heavy drinkers are poorer risks than those who abstain. It is difficult to say that limited or moderate use of alcohol shortens life. But no one can deny that even moderate drinking of alcoholic beverages increases the possibility of accidental death. It also lowers body resistance and increases the possibility of death from infectious disease, especially tuberculosis. There is no question that heavy drinking shortens life considerably.

Alcohol and society. The effects of alcohol are much more far-reaching than damage to the habitual drinker himself. His family and all society pay a price for his shortsightedness. Often an alcoholic will neglect his family to satisfy the desire for alcohol. Child neglect, loss of job, divorce, and other acute domestic problems frequently result. Anxiety, frustration, and insecurity in children are a terrible price to pay for alcoholism. Alcohol must also answer for much of the crime committed in America. In a recent study of the records of 13,402 convicts in 12 states, alcohol was found to be a contributing factor in 50 percent of the crimes committed, and a direct cause of 16.8 percent of the crimes.

Alcohol and driving. Important experiments have recently been carried on in Pennsylvania to test thoroughly, under actual road conditions, the relation of drinking to driving a car. Motorists who have been given measured amounts of alcohol but who were not drunk (all but one passed the standard police sobriety tests) were found to make all sorts of accidental errors. Not only did most of these drivers have a slower braking reaction time, but they were also inaccurate in performance. Yet every one of these drivers thought he was doing well. The fundamental trouble, graphically proved by psychological tests, was found to be the *impairment of judgment after only one or two drinks.*

The death toll from automobiles is over 100 per day with over 3,000 more people injured per day. Safety officials directly attribute from 7 to 10 percent of fatal highway accidents to the use of alcohol, while competent traffic officials state that a third of these accidents is indirectly caused by the driver's alcoholic indulgence.

The effects of alcohol on a driver of a car are as follows:

1. Less attention to signals and driving hazards.
2. Slower responses of eyes, hands, and feet, due to increased reaction time.
3. Increased self-assurance, which causes a driver to take chances and be less considerate of other drivers.

Narcotic drugs. By discussing problems relating to alcohol and narcotic drugs in the same chapter, we do not mean to imply that the problems are similar. Many people consume alcoholic beverages without becoming habitual drinkers or alcoholics. Continued use of narcotic drugs, however, results in both mental and physical ***addiction.*** That is, the victim becomes dependent on the mental and emotional effects of the drug and his body develops a need for it. When not under the influence of a narcotic, the addict develops violent ***withdrawal symptoms.*** These include sleeplessness, difficulty in breathing, irregular heart action, and acute suffering. Mental symptoms include severe depression and derangement. Withdrawal sickness may be severe enough to cause death. The longer an addict uses a narcotic, the greater amount he must take to ward off the withdrawal sickness.

45-3 "If you drive, don't drink; if you drink, don't drive." Traffic officials estimate that one third of all automobile accidents are either direct or indirect results of drinking. (Wide World Photos)

A *narcotic* is a drug designated as such by the federal government because it results in addiction if used without medical direction. The sale of narcotics, except on a doctor's prescription, is illegal.

Opium is the source of a family of narcotic drugs. It is extracted from the juice of the white poppy. *Morphine* and *codeine* are derived from opium. *Heroin* is a synthetic compound prepared from morphine. Morphine is used to reduce pain. Codeine has similar uses and is an ingredient in special kinds of medicines, including some cough syrups. Heroin is so dangerous and addicting that its possession or use in the United States, even for medical purposes, is illegal.

Cocaine is a narcotic drug extracted from the leaves of the South American coca plant (not connected with the beverage cocoa). Cocaine deadens skin and mucous membranes. A doctor may use it to deaden the area around a wound before he cleanses it or takes stitches. When taken internally, cocaine causes a temporary stimulation of the nervous system and a feeling of pleasure. Later, however, the victim is seized by a feeling of great fear and may even become violent.

A weed called *marijuana* (mar-i-*wha*-nuh) often receives considerable attention in the newspapers as a narcotic. It is usually mixed with tobacco and smoked. The marijuana user develops an emotional addiction to the effects of the drug but does not experience physical addiction. However, marijuana addicts usually continue down the narcotic road to ruin, as they eventually turn to opiates.

The narcotic menace. People may become narcotic addicts in several ways. Some people become addicted after an illness in which a narcotic drug was used medically to relieve pain. Highly nervous or distressed people may use certain narcotics as depressants and continue purchase of the drugs illegally. Still others who are emotionally disturbed or maladjusted deal with dope peddlers who are associated with the organized and unlawful sale of narcotics.

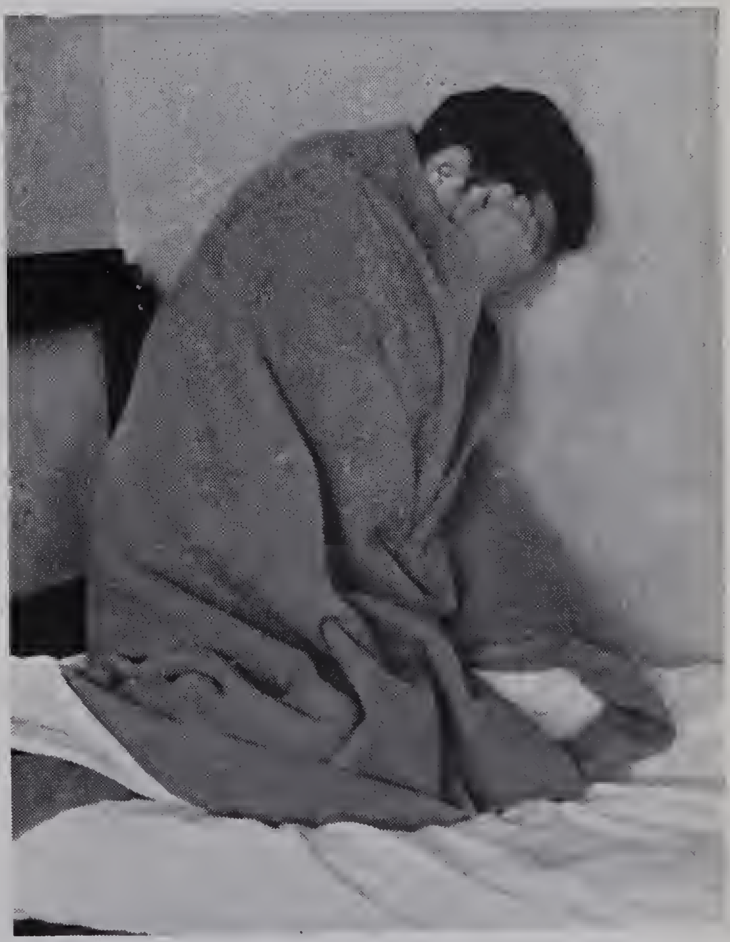
Once a person starts to use an addicting drug such as heroin, he starts down the shortest and surest road to ruin. The process takes only a few weeks. The narcotic addict becomes absolutely useless to himself or anyone else. He cannot hold a job. He withdraws from his family and friends to live alone with his drug and needle.

There are approximately 60,000 addicts in the United States today. For most of these people crime is a necessary way of life. They are forced to steal to pay the fantastic prices exacted in the illegal narcotics traffic. Of the addicts who are treated in the two federal narcotics hospitals, less than one fourth stay off drugs after their release. Many of these are teen-agers, some as young as 13 or 14.

Several things can happen to an addict. He can ask for treatment, which is often unsuccessful. He can be arrested for illegal possession of narcotics. He can die from an overdose, an infected needle, or suicide. The only way to avoid these tragedies is never to start taking a narcotic.

The barbiturate problem. The ***barbiturates*** are synthetic drugs that act as sedatives. They are commonly called sleeping pills. Although it is not generally known, hundreds of thousands of people in this country use barbiturates habitually. Barbiturates are not addicting in the sense that narcotic drugs are, but victims develop a psychological dependence on them and may even have withdrawal symptoms when they are taken away. Aside from the degrading dependence, there are two severe hazards of barbiturates: they are fatal in combination with excess alcohol, and they are frequently used for suicide.

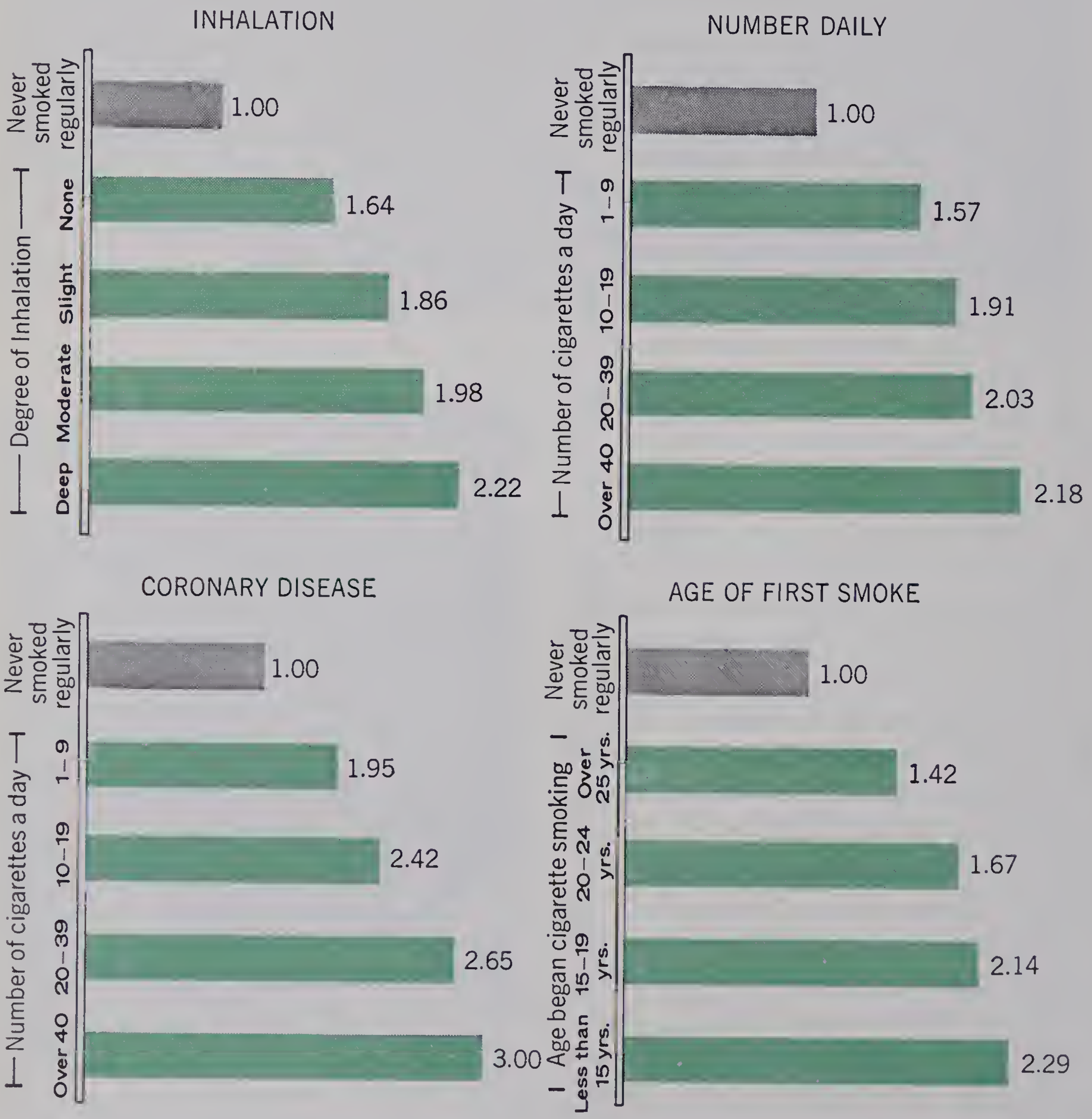
Tobacco – the nation's leading habit. More than 70 million people in the United States use tobacco in some form. The great majority of these are cigarette smokers. The smoker actually becomes a slave to two habits: the smok-



45-4 Painful, grotesque withdrawal symptoms occur when a narcotic addict is completely taken away from his drug. (Wide World Photos) ing habit and the tobacco habit. The first involves reaching for a cigarette at regular intervals, lighting it, and going through the various movements associated with smoking. Heavy smokers often light a second cigarette even before finishing the first one. They also acquire a physiological craving for the nicotine in tobacco — the tobacco habit.

Most young people who start smoking feel that it makes them seem more mature. Yet, if they asked the advice of an older person who has smoked for several years, his advice would undoubtedly be not to start. Certainly several things should be considered before deliberately starting a practice as habit-forming and as dangerous to health as smoking.

The effects of smoking. In 1964 the Public Health Service published a report on the effects of smoking based on experiments with animals, clinical and autopsy studies in man, and studies of



45-5 These graphs show ratios of death rates in the age group 40–69. The death rate for nonsmokers is given as 1.00; the other numbers are ratios compared to this base number. (Adapted from a report by E. C. Hammond) the occurrence of disease in the population. Included in the report were the following findings:

Tissue damage: Sections of lung tissue from thousands of smokers have been examined after death. Even in individuals who did not die of cancer, abnormal cells were found in the lungs. Enlarged and ruptured alveoli and thickened arterioles were observed. In the trachea and bronchi, cilia and the protective cells of the mucosa were destroyed. Remember that these structures normally cleanse and lubricate the respiratory tract and help to prevent infection.

Increased death rate: For the purposes of this study the number of deaths among a large sample of nonsmokers was compared to the number of deaths among a similar sample of smokers. There were 70 percent more deaths from all causes among smokers than among nonsmokers. The greater number of deaths from certain diseases among smokers was particularly marked. There were 1000 percent more deaths from lung cancer and 500 percent more from chronic bronchitis and the degenerative lung disease called emphysema. The death rate was also considerably higher for cancer of the tongue, larynx, and esophagus, for peptic ulcer, and for circulatory diseases.

Increase of death rate with the amount smoked: In general the greater the number of cigarettes smoked, the higher the death rate. For men who smoke less than ten cigarettes a day, the death rate is about 40 percent higher than for nonsmokers. For those who smoke 40 or more it is 120 percent higher. The same kind of relationship exists between the number of years of smoking and the death rate.

It should be obvious from these findings that smoking is a health hazard. To put the figures on lung cancer in another way, 95 percent of the victims of lung cancer are heavy smokers. One half of one percent are nonsmokers. Lip cancer has definitely been traced to irritation from a pipe or cigar. Lung and lip cancer, however, do not account for a large percentage of deaths in this country. Heart and circulatory diseases are the number one cause of death in the United States. The death rate for these diseases is 200 percent higher among smokers.

Aside from the long-term effects, smoking has many short-term disadvantages. It is an expensive habit, and gets more so every year. It is messy and often annoying to other people. Smoking stains the teeth and fingers and makes the breath unpleasant. Certainly no one's appearance is improved by a cigar or cigarette hanging from his mouth. Smoking causes constant throat irritation, stomach discomfort, nervousness, and sometimes headaches.

IN CONCLUSION

Alcohol is a depressant that has no relation to the energy needs of the body. Its habitual use may lead to alcoholism, various organic diseases, and even death.

Narcotic addiction is one of the worst medical and social problems in the country today. The narcotic road is one-way. It leads all too suddenly to complete physical, moral, and mental ruin.

While tobacco is not addicting in the sense that narcotic drugs are, the various ways in which cigarette smoking is dangerous to health are becoming more obvious with each year of further research.

BIOLOGICALLY SPEAKING

addiction
alcoholism
barbiturate
cirrhosis
cocaine
codeine
delirium tremens
depressant
fatty liver
gastritis
heroin
marijuana
morphine
narcotic
opium
withdrawal symptoms

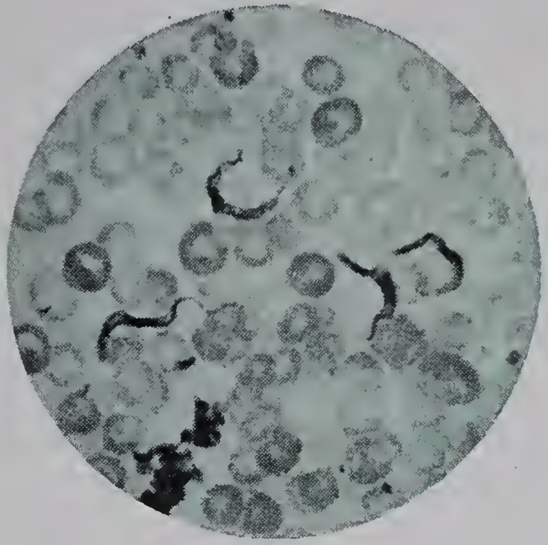
QUESTIONS FOR REVIEW

1. Why is alcohol not considered a food?
2. What happens when alcohol enters the body?
3. What organs of the body are especially affected by alcohol?
4. Why is alcohol not considered a stimulant?
5. Where in the nervous system does alcohol first have an effect? What are the results of this effect?
6. Why is it dangerous for a person who has had an alcoholic drink to drive an automobile?
7. Name six definite narcotic drugs as defined by the federal government.
8. In what ways is it possible to become a narcotic addict?
9. What are some of the findings concerning the death rate among smokers?
10. What are some of the short-term disadvantages of smoking?

APPLYING PRINCIPLES AND CONCEPTS

1. Why is drinking alcohol on an empty stomach more injurious than drinking with meals or after eating?
2. Why does the presence of alcohol in the body give a person a feeling of warmth?
3. Why do life insurance companies always ask the applicant if he drinks, or smokes, and to what extent?
4. Explain the possible relationship between drug addiction and juvenile delinquency. How do drug addicts and alcoholics show character weakness?
5. Why is inhaling smoke more injurious than not inhaling?

CHAPTER 46



BODY REGULATORS

What are the ductless glands? You are already familiar with some glands, such as the salivary glands of the mouth and the gastric glands of the stomach. These pour secretions into the digestive tract through ducts. The ductless glands, which we shall study in this chapter, are entirely different from the digestive glands. The name *ductless* indicates that they have no ducts leading from them; their secretions enter the blood stream directly. With blood as a transporting medium, these secretions reach every part of the body and influence all the organs. Ductless glands are also called ***endocrine*** (*en*-do-krin) ***glands.***

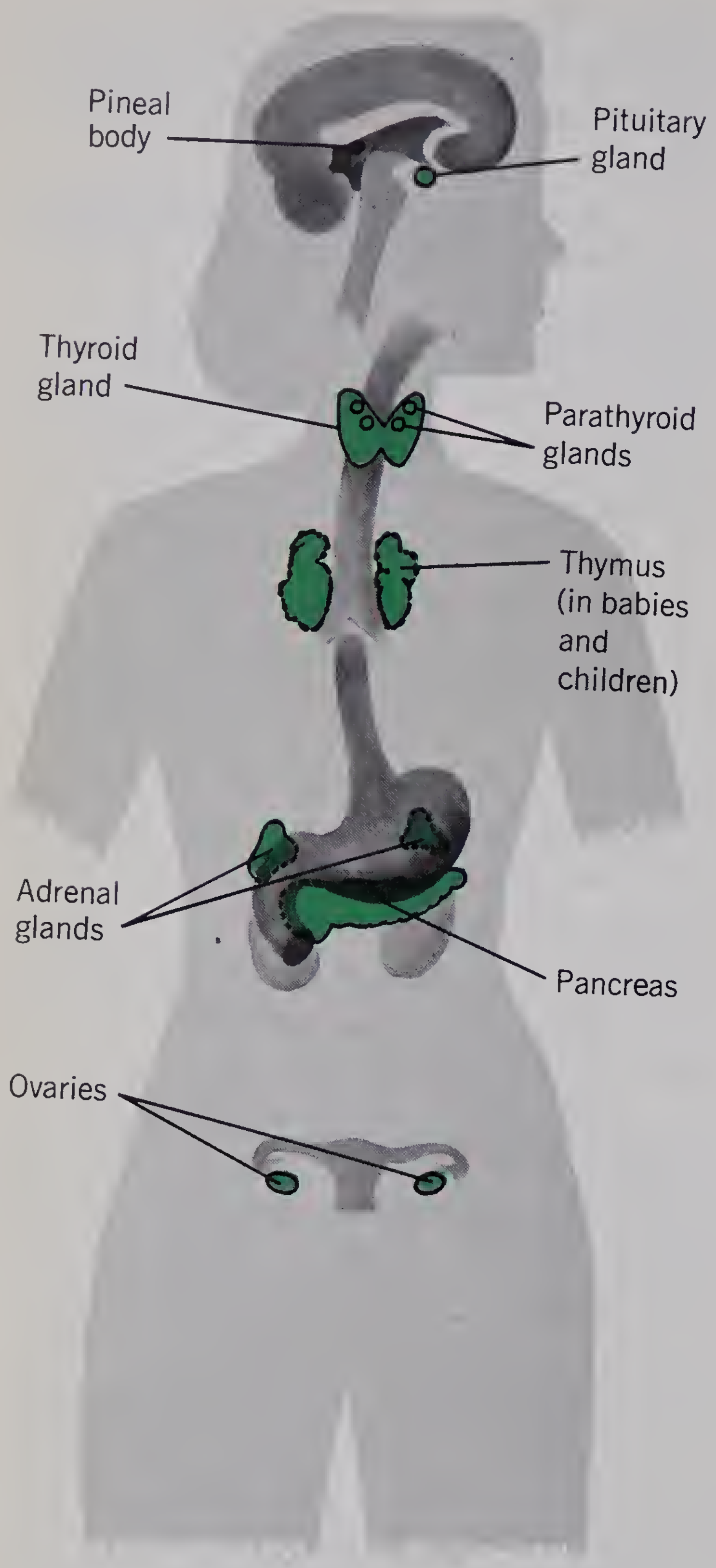
We call the secretions of ductless glands ***hormones.*** These chemicals are formed from substances taken from the blood. They regulate the activity of all the body processes. Thus the circulatory system is vital to the endocrine system, both in supplying the raw materials and in delivering the finished product. For the most part the endocrine glands are small. Their size is entirely out of proportion to the vital influence they exert on the body.

As you study the various glands, you may want to refer to Fig. 46–1 and to the summary table on page 645.

The thyroid gland and its hormone. You are probably more familiar with the ***thyroid*** than with any of the other endocrine glands. The gland is relatively large and lies close to the body surface, in the neck near the junction of the lower part of the larynx and the trachea. The thyroid consists of two lobes connected by an isthmus (Fig. 46–2). The lobes lie on either side of the trachea and extend upward along the sides of the larynx. The isthmus extends across the front surface of the trachea. As Fig. 46–2 shows, the complete thyroid gland somewhat resembles a butterfly with its wings spread.

The thyroid hormone contains a substance called ***thyroxine,*** which has the highest relative concentration of *iodine* of any substance in the body. From this you can understand why iodine is essential for normal functioning of the body. Commercially the thyroid hormone is prepared by extraction from the thyroid glands of sheep. After being purified it is called *thyroid extract* and is used in treating thyroid disorders. Thyroid extract is the least expensive of any commercial endocrine preparation.

The thyroid and metabolism. The thyroid hormone regulates the rate of metabolism. In this way it influences growth and oxidation. Overactivity of the thyroid gland, or ***hyperthyroidism,*** increases the rate of oxidation and raises the body temperature. Heart action increases and blood pressure rises. Sweating, when the body should be cool, is a



46-1 Diagram showing the location of the endocrine glands in the female. Why are they called ductless glands?

common symptom of this condition. The individual also becomes extremely nervous and irritable. Some victims develop characteristic bulging eyes and a staring expression.

Hyperthyroidism used to be treated solely by surgery, but recently treatment with a drug called *thiouracil* (thy-oh-*yur*-a-sil) has been found to be effective. Another treatment for hyperthyroidism consists of dosage with radioactive iodine. This is picked up by the gland as ordinary iodine would be. It then bombards the gland with radioactivity and destroys some of the gland tissue, as surgery formerly did.

Underactivity of the thyroid gland, called ***hypothyroidism***, produces the opposite symptoms. The rate of oxidation is decreased and activity of the nervous system is reduced. This produces characteristic physical and mental retardation. Heart action decreases and in many cases the heart enlarges. Both overactivity and underactivity of the thyroid gland may be determined by measuring the rate of basal metabolism. Hypothyroidism may be treated with thyroid extract.

If the thyroid is defective during infancy, ***cretinism*** results. This condition is characterized by stunted physical and mental development. The face usually becomes bloated, the lips greatly enlarged, and the tongue thick and protruding from the mouth. If the cretin passes from infancy to childhood without treatment with thyroid extract, the dwarfism and mental deficiency can never be corrected.

If the thyroid stops working during adult life, ***myxedema*** (mik-se-*dee*-ma) results. This causes coarsening of the features and swollen eyelids. Often mental ability suffers. Like cretinism, myxedema can be corrected with thyroid extract if treatment is started early.

Iodine deficiency is the major cause of enlargement of the thyroid gland, known as ***simple goiter***. This condition is rare along the seacoast where people eat an abundance of seafoods containing iodine. It is more common in mountainous regions and in the Great

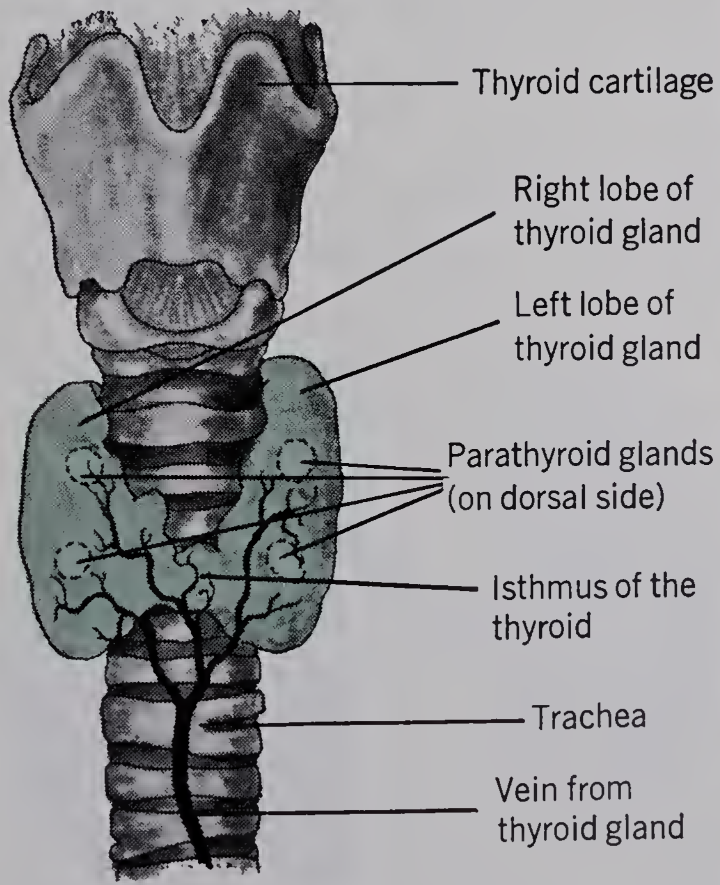
Lakes basin where the iodine content of the soil is low. The addition of iodine compounds to table salt and to the water supply in certain regions is an adequate preventive measure.

The parathyroid glands. The ***parathyroids*** are four small glands embedded in the back of the thyroid, two in each lobe (Fig. 46–2). Their secretion, ***parathormone,*** controls the use of calcium in the body. Bone growth, muscle tone, and normal nervous activity are absolutely dependent on a constant, stable calcium balance.

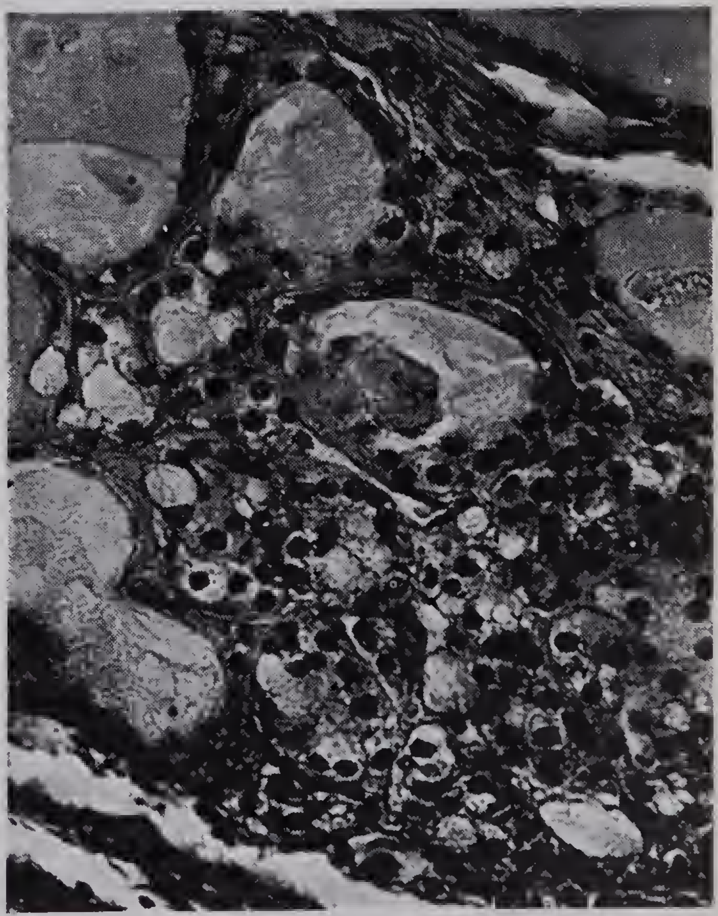
The pituitary gland. The small ***pituitary,*** a gland about the size of an acorn, lies at the base of the brain. It was once called the "master gland," since its secretions influence the activity of all other glands. It is now known that other glands, especially the thyroid and adrenals, in turn influence the pituitary.

The pituitary gland consists of two lobes: anterior and posterior. The ***anterior lobe*** secretes several different hormones. One of these, the ***somatotropic hormone,*** or *growth hormone,* regulates the growth of the skeleton. Other secretions of the anterior lobe of the pituitary gland, the ***gonadotropic hormones,*** influence the development of the reproductive organs. It also influences the hormone secretion of the ovaries and testes. The gonadotropic hormone, together with the sex hormones, cause the sweeping changes that occur during adolescence, when the child becomes an adult.

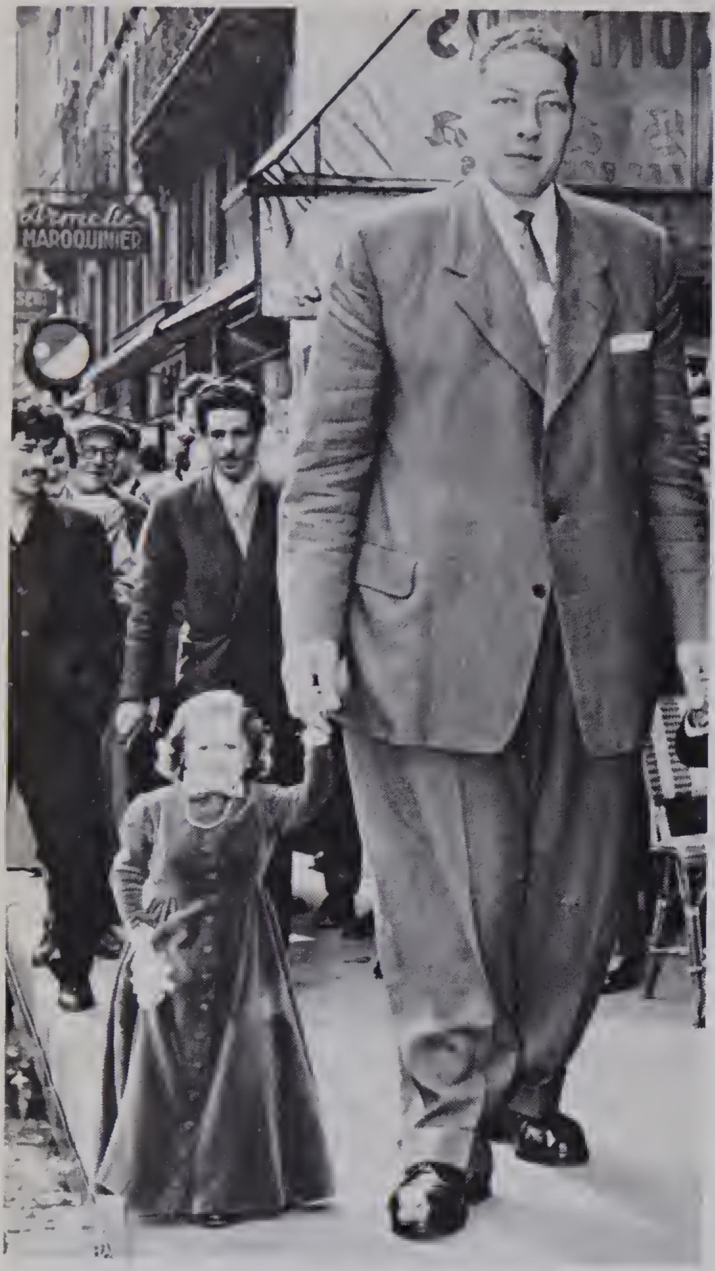
Other secretions of the anterior lobe of the pituitary gland include hormones that stimulate the secretion of milk in the mammary glands (*lactogenic hormone*), and the activity of the thyroid gland (*thyrotropic hormone*).


Thyroid cartilage
Right lobe of thyroid gland
Left lobe of thyroid gland
Parathyroid glands (on dorsal side)
Isthmus of the thyroid
Trachea
Vein from thyroid gland

46-2 Note the position of the thyroid gland in relation to the trachea. Note also the four parathyroid glands embedded in the back of the thyroid.



46-3 A section of human thyroid tissue. The large areas are follicles into which the hormone is secreted from surrounding cells. (Walter Dawn)



46-4 If the anterior lobe of the pituitary gland produces too little of the somatropic hormone, a midget may result. What happens when there is considerable oversecretion of this growth hormone? (United Press International)

ACTH (*adrenocorticotropic hormone*) is another secretion of the anterior lobe of the pituitary gland; it stimulates the outer part, or cortex, of the adrenal glands. ACTH has been used in the treatment of leukemia and more successfully in the treatment of arthritis. Good results in the treatment of asthma and other allergies with ACTH have also been reported. Even though ACTH may not permanently cure these diseases, its use may lead the way to the discovery of their actual causes.

The *posterior lobe* of the pituitary gland produces two hormones: ***oxytocin,*** which helps regulate the blood pressure and stimulates smooth muscle; and ***vasopressin,*** which controls water resorption in the kidneys. Oxytocin is administered during childbirth to cause contraction of the uterus.

Vasopressin deficiency causes a condition called ***diabetes insipidus*** (in-*sip*-id-us), in which the craving for water is constant. This disease should not be confused with true diabetes, which we shall discuss in connection with the pancreas.

Disorders of the pituitary gland. The most frequent disorder of the pituitary involves the somatotropic hormone. If an oversecretion of this hormone occurs during the growing years, a ***giant*** may result. There are circus giants over 8 feet tall who weigh over 300 pounds and wear size 30 shoes. If the oversecretion occurs during adult life, the bones of the face and hands thicken, since they cannot grow in length. The organs and the soft tissues enlarge tremendously. This condition is known as ***acromegaly*** (ak-roh-*meg*-a-lee). Victims of this disorder have greatly enlarged jawbones, noses, and hands and fingers.

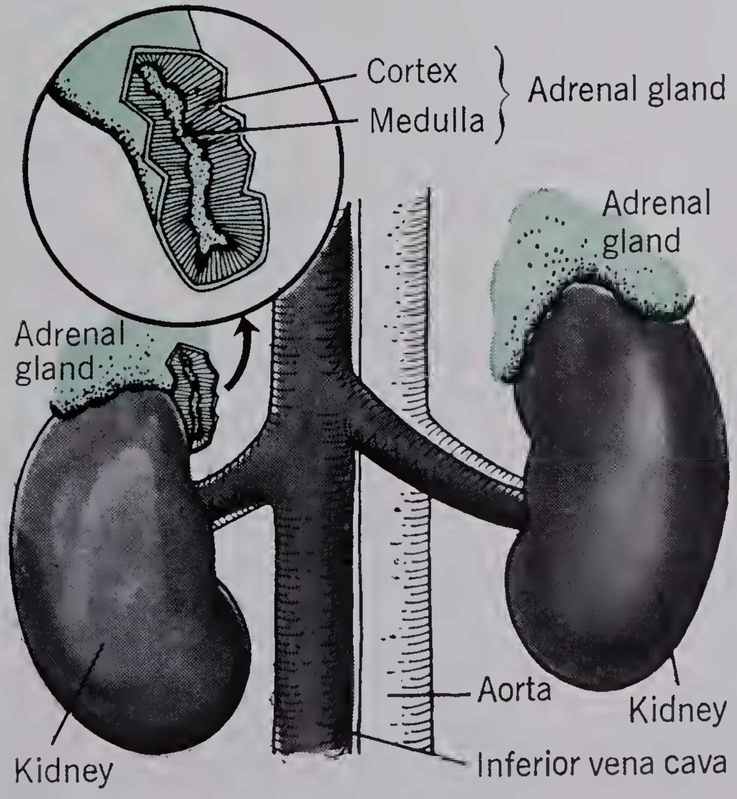
Somatotropic hormone deficiency results in a pituitary dwarf, or ***midget.*** These individuals are perfectly proportioned men in miniature. They are quite different from the thyroid dwarf in that they have normal intelligence.

The glands of emergency. The ***adrenal glands,*** also called *suprarenals,* are located on top of each kidney (Fig. 46–5). They are composed of an outer region, the ***cortex,*** and an inner part, the ***medulla.*** Unlike the adrenal medulla the adrenal cortex is absolutely essential for life. It secretes a hormone complex called ***cortin.*** These hormones are responsible for the control of certain phases of carbohydrate, fat, and protein metabolism as well as of the salt and water balance in the body. The adrenal cortex also yields hormones that control the production of some types of white corpuscles and the structure of connective tissue.

Addison's disease results from damage or destruction of the adrenal cortex, which often occurs as a result of tuberculosis. Symptoms include fatigue, nausea, loss of weight, general circulation failure, and changed skin color. Treatment with the compound in cortin called *cortisone* is effective.

The medulla secretes a hormone called ***epinephrine*** (ep-i-*nef*-reen), or *adrenaline*. The adrenal glands have been called the glands of emergency because of the action of this hormone. Many people have performed superhuman feats of strength during periods of anger or fright, with the help of epinephrine. This strength of desperation results from a series of rapid changes in body activity.

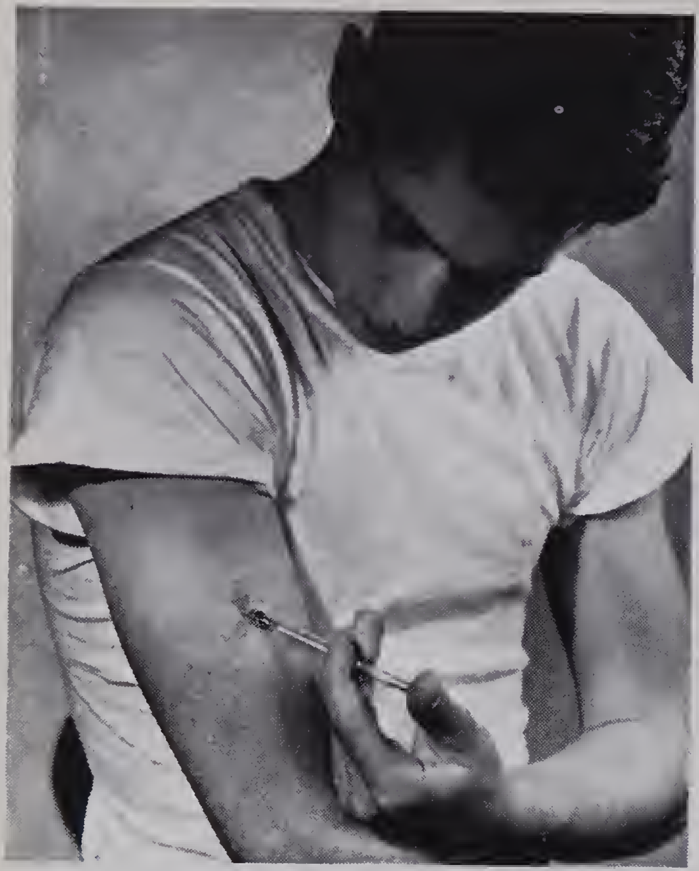
1. The person becomes pale, because of constriction of the blood vessels in the skin. The rapid movement of blood from the body surfaces reduces loss of blood if there is a surface wound. It also increases the blood supply to the muscles, brain, heart, and other vital organs.
2. The blood pressure rises, because of constriction of surface blood vessels.
3. The heart action and output are increased.
4. The liver releases some of its stored sugar and provides material for increased body activity and oxidation.



46-5 Notice the position of the adrenal glands in relation to the kidneys. What two important hormones do these glands secrete?

The pancreas. The production of pancreatic fluid in connection with digestion is only part of the function of the ***pancreas.*** Special groups of cells, called ***islets of Langerhans,*** secrete the hormone ***insulin.*** This hormone enables the liver to store sugar as glycogen and regulates the oxidation of sugar.

A person who lacks insulin cannot store or oxidize sugar efficiently. Thus the tissues are deprived of food, and sugar collects in the blood. As the blood sugar rises, some of it is excreted in the urine. Doctors call this condition ***diabetes mellitus*** (me-*ly*-tus). Diabetes mellitus, however, is probably not only simple failure of the islet cells of the pancreas to produce insulin. The pituitary, thyroid, and adrenal glands, as well as the liver, are known to play an important part in the disease. Body weight also influences the appearance of this condition. Diabetes mellitus is definitely hereditary. If you have it in your family, regular periodic checkups for sugar in the urine should be made by your family doctor. There is no cause for alarm if the disease appears, for once discovered, it can usually be



46-6 A diabetic learns to inject himself with insulin and also to control his diet so he may lead a normal life. (New York Diabetes Association, Inc.)

controlled successfully. If treatment is begun in the early stages, the patient can lead a perfectly normal life.

Production of excess insulin results in a condition called ***hypoglycemia,*** which means, literally, "low blood sugar." Excess insulin in the blood causes sugar that should be delivered to the cells to be stored in the liver. The fatigue caused by hypoglycemia is treated by a diet controlled in its carbohydrate content.

The ovaries and testes. The ***ovaries*** of the female and the ***testes*** of the male have dual functions. We think of them primarily as organs for the production of eggs and sperm. However, certain cells of the ovaries and the testes serve as ductless glands. These ovary cells secrete the female hormones ***estrogen*** (*es*-troh-jen) and ***progesterone*** (proh-*jes*-ter-ohn). Special cells of the testes produce the male hormone ***testosterone*** (tes-*tos*-ter-ohn). This hormone can now be produced artificially, and is used in treating sex hormone disturbances in both males and females. Furthermore, the production of this hormone is not limited to the testes. It is secreted by the cortex of the adrenal glands in both males and females. In the female the estrogen secreted in the ovaries normally neutralizes the effects of the testosterone from the adrenal glands. However, if the estrogen secretion in the ovaries is reduced, the female may become mannish. Similarly, reduced production of testosterone in the testes of the male can result in feminine tendencies. Thus different individuals may represent various degrees of maleness and femaleness.

Sex hormones control the development of the secondary sex characteristics that appear in the change from childhood to adulthood. These changes first appear with the maturation of the ovaries and testes during the period called ***puberty.*** In the animal world these characteristics may appear as the large comb of the rooster, the bright plumage of most male birds, and the antlers of the deer. Many secondary characteristics are appearing and have appeared in your own body. As a boy approaches puberty, his voice cracks and then deepens. His beard appears along with a general increase in body hair. The chest broadens and deepens. Rapid growth of the long bones adds to his height. As a girl matures, her breasts develop and her hips broaden, because of the formation of fat deposits under the skin, and menstruation begins. These physical changes in both boys and girls are accompanied by sweeping mental and emotional changes. Compare your present personality with that of a child ten

DUCTLESS GLANDS AND THEIR SECRETIONS

Gland	*Location*	*Hormone*	*Function of Hormone*
Thyroid	Neck, below larynx	Thyroid hormone	Accelerates the rate of metabolism
Parathyroids	Back surface of thyroid lobes	Parathormone	Controls the use of calcium in the tissues
Pituitary	Base of brain		
Anterior lobe		Somatotropic hormone	Regulates growth of the skeleton
		Gonadotropic hormone	Influences development of sex organs and hormone secretion of the ovaries and testes
		ACTH	Stimulates secretion of hormones by the cortex of the adrenals
		Lactogenic hormone	Stimulates secretion of milk by mammary glands
		Thyrotropic hormone	Stimulates activity of the thyroid
Posterior lobe		Oxytocin	Regulates blood pressure and stimulates smooth muscles
		Vasopressin	Controls water resorption in the kidneys
Adrenal	Above kidneys		
Cortex		Cortin (a hormone complex)	Regulates metabolism, salt, and water balance Controls production of certain white corpuscles and structure of connective tissue
Medulla		Epinephrine	Causes constriction of blood vessels, increase in heart action and output, stimulates liver and nervous system
Pancreas	Below and behind stomach		
Islets of Langerhans		Insulin	Enables liver to store sugar and regulates sugar oxidation in tissues
Ovaries	Pelvis		
Follicular cells		Estrogen	Produces female secondary sex characteristics; influences adult female body functions
		Progesterone	Maintains growth of the mucous lining of the uterus
Testes	Below pelvis		
Interstitial cells		Testosterone	Produces male secondary sex characteristics

to twelve years old and you will see how these glands have influenced you. These glands will be discussed further in the next chapter.

The pineal body and thymus. The ***pineal body*** is a mass of tissue about the size of a pea, located at the base of the brain. It lies directly behind the junction of the spinal cord and brain tissue. This body may or may not be a ductless gland. No hormone secretion from the pineal body has been discovered, and we do not know what its function is.

The ***thymus,*** too, may be a ductless gland, but no endocrine secretion has been identified with it. It lies just above the heart, under the breastbone. At birth the thymus weighs less than half an ounce. It increases in size during childhood and reaches its maximum size between the ages of 12 and 14. During the time when it is maximum size, the thymus gland usually weighs about one ounce, or twice its weight at birth. During adulthood it gradually grows smaller and finally shrinks to the size it was at birth. The thymus is a center of the production of cells called *lymphocytes.* Recent research indicates that these cells may be the parent cells of those that produce antibodies in the lymph nodes and spleen. Thus the thymus may be important in the body's defenses against disease.

Dynamic balance in the endocrine glands. We have seen that too much or too little of a hormone can upset the balance that the endocrine glands normally maintain in the body. We have also seen that one gland can influence the activity of others. Besides the influence of glands on one another, there are two other factors operating to produce the delicate check-and-balance system in body chemistry.

In the first of these factors, called ***feedback,*** the accumulation of a substance in the blood automatically cuts down its production by the endocrine gland. For example, remember that parathormone regulates the level of calcium in the body. The concentration of calcium in turn regulates the production of parathormone. When the calcium level in the body drops, the secretion of parathormone increases to restore the calcium level. When the proper level is reached, the calcium influences the parathyroids to decrease their secretion. This same kind of feedback occurs in the other glands and between various glands. In this way a balanced state is automatically maintained in the normally functioning body.

The endocrine glands are also affected by the activity of the nervous system, which acts as a monitor of both internal and external conditions. The adrenal medulla, for example, may be stimulated to produce epinephrine as the need is signaled by the sympathetic nervous system. Nervous control and feedback are further examples of homeostatic mechanisms operating in the body to maintain a steady state in the face of constantly changing conditions.

IN CONCLUSION

Ductless glands secrete hormones directly into the blood stream. These hormones influence body metabolism, growth, mental capacity, chemical balance in the body fluids, and many other functions. Glands are controlled by feedback and by nervous control, as well as by one another.

In this chapter you have studied some of the endocrine functions of the ovaries and testes. In the chapter to follow you will study the primary function of these organs, that of producing the sex cells for reproduction.

BIOLOGICALLY SPEAKING

acromegaly
Addison's disease
adrenal cortex
adrenal glands
adrenal medulla
ACTH
cortin
cretinism
diabetes insipidus
diabetes mellitus
endocrine gland
epinephrine
estrogen
feedback
giant
gonadotropic hormones
hormone
hypoglycemia
hyperthyroidism
hypothyroidism
insulin
islets of Langerhans
midget
myxedema
ovaries
oxytocin
pancreas
parathormone
parathyroid glands
pineal body
pituitary gland
progesterone
puberty
simple goiter
somatotropic hormone
testes
testosterone
thymus
thyroid gland
thyroxine
vasopressin

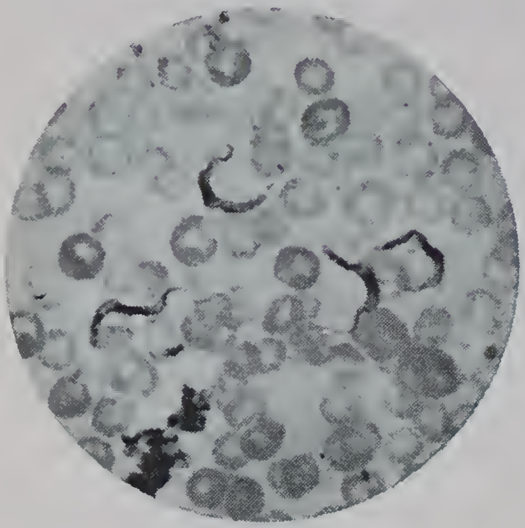
QUESTIONS FOR REVIEW

1. What role does the blood play in the function of endocrine glands?
2. How does the thyroid gland regulate the rate of metabolism?
3. Explain how hyperthyroidism and hypothyroidism can affect personality.
4. In what ways do the pituitary and thyroid glands influence growth?
5. How does the pituitary gland affect the sex glands?
6. Compare the body characteristics of a thyroid dwarf and a pituitary dwarf. How do they differ and in what ways are they similar?
7. What is ACTH? What is its function?
8. In what ways are puberty and adolescence a result of glandular activity?
9. Why does sugar appear in the urine of a diabetic?

APPLYING PRINCIPLES AND CONCEPTS

1. What gland has a hormone that may influence intelligence?
2. How do you account for the fact that the heartbeat of a basketball player increases a great deal before the game as well as during it?
3. Why is a study of the endocrine glands often included with a study of the nervous system?
4. What hormone injected into the blood stream of a male rat will often result in a mothering instinct? Why?
5. Discuss dynamic balance in the endocrine system resulting from feedback.

CHAPTER 47

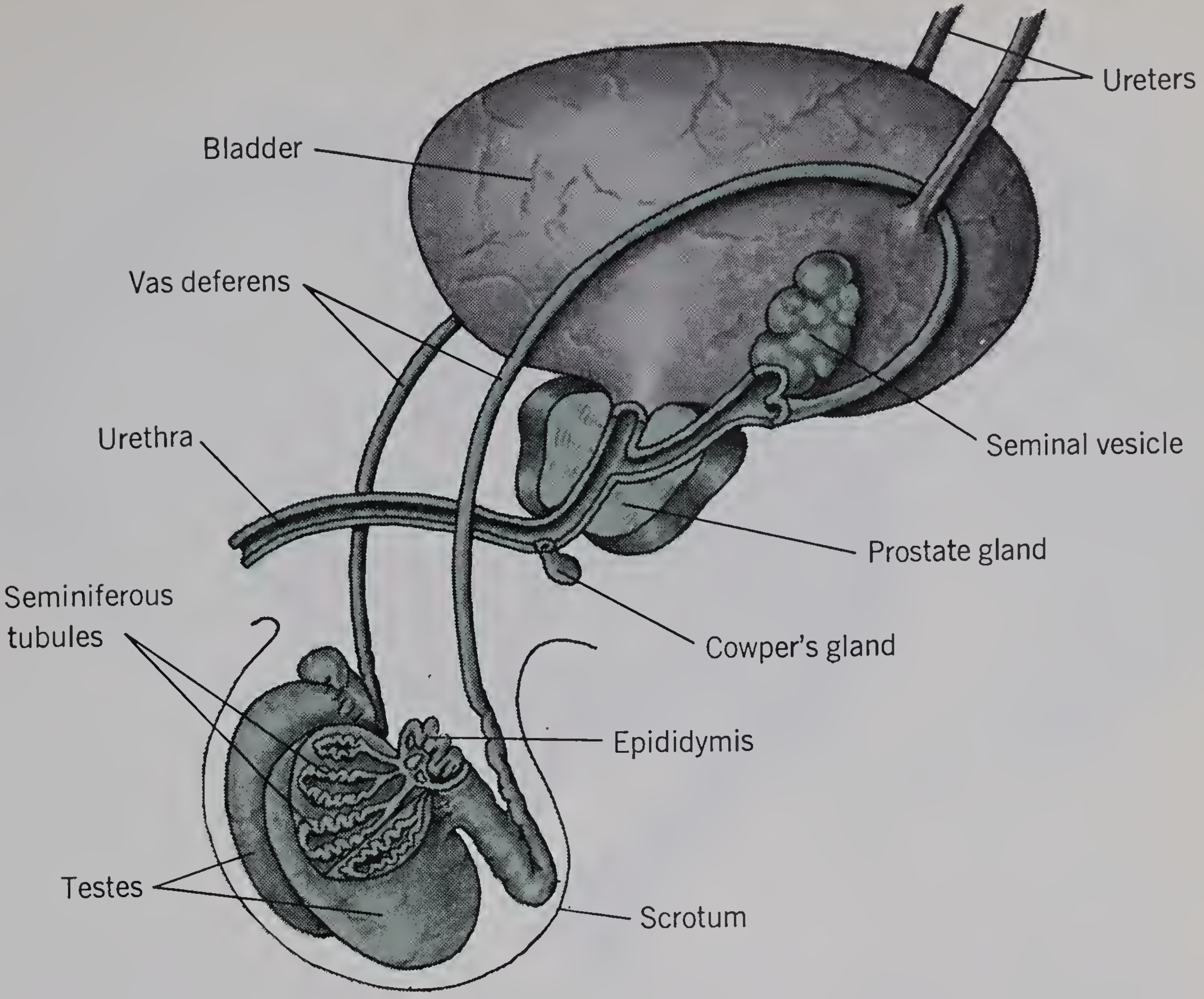


REPRODUCTION AND DEVELOPMENT

The significance of sexual reproduction. At this time it might be a good idea to review the significance of the process of sexual reproduction, which you first studied in Unit I. The union of two gametes to form a zygote that is capable of growing into an organism resembling the parents constitutes sexual reproduction. Gamete production occurs in the gonads. During the meiotic division of gamete formation, the chromosome pairs separate, resulting in haploid cells. The mechanism of the separation of chromosome pairs assures variation in the genetic composition of the gametes. Figure 8–7, page 111, shows how meiosis produces the haploid number of chromosomes in gamete production. When fertilization forms the zygote, the diploid number of chromosomes is restored, with each parent contributing one chromosome to each pair. The genes then begin their influence on the development of a new organism. All the zygotes of a species contain genes that control the method of development to create an individual resembling the species. At the same time the combination of genes for unlike characteristics produces offspring that vary from each parent.

Organisms that reproduce asexually, in a one-parent system, do not have this possibility of variation that results from the combination of unlike genes from two parents. Remember that variations in offspring sometimes result in favorable adaptations that improve the species. Although favorable mutations may occur occasionally in asexual organisms, their ability to adapt is greatly lessened by the one-parent system.

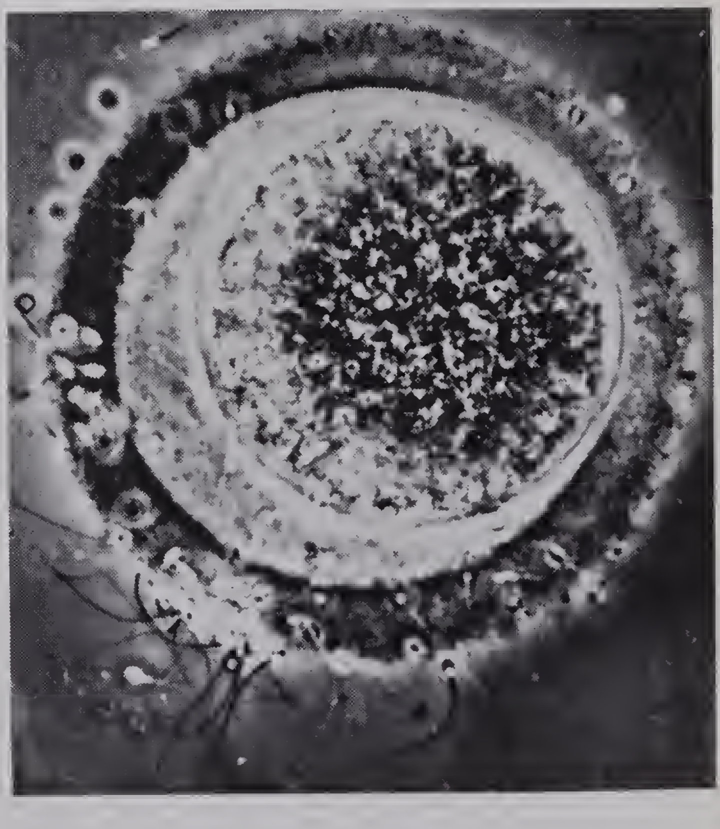
The male reproduction system. The male gonads are the ***testes*** and are located outside the body in a pouch of skin called the ***scrotum*** (Fig. 47–1). Although these paired organs produce a male hormone concerned with the development of secondary sex characteristics (see Chapter 46), the testes have the other important function of producing sperm. The highly coiled tubes within the testes are the ***seminiferous tubules*** (sem-i-*nif*-e-rus *too*-byoolz). The haploid sperm, formed by meiotic divisions of the cells in the testes, are carried to the ***epididymis*** (ep-i-*did*-i-mis) for storage, by the action of ciliated cells of the seminiferous tubules. The ***vas deferens*** (*vas def*-e-renz) is a duct that carries the sperm from the epididymis past the ***seminal vesicle.*** A short tube connects the seminal vesicle to the urethra by passing through the ***prostate gland*** and another small organ called ***Cowper's gland.*** These three structures


Ureters
Bladder
Vas deferens
Seminal vesicle
Urethra
Prostate gland
Seminiferous tubules
Cowper's gland
Epididymis
Testes
Scrotum

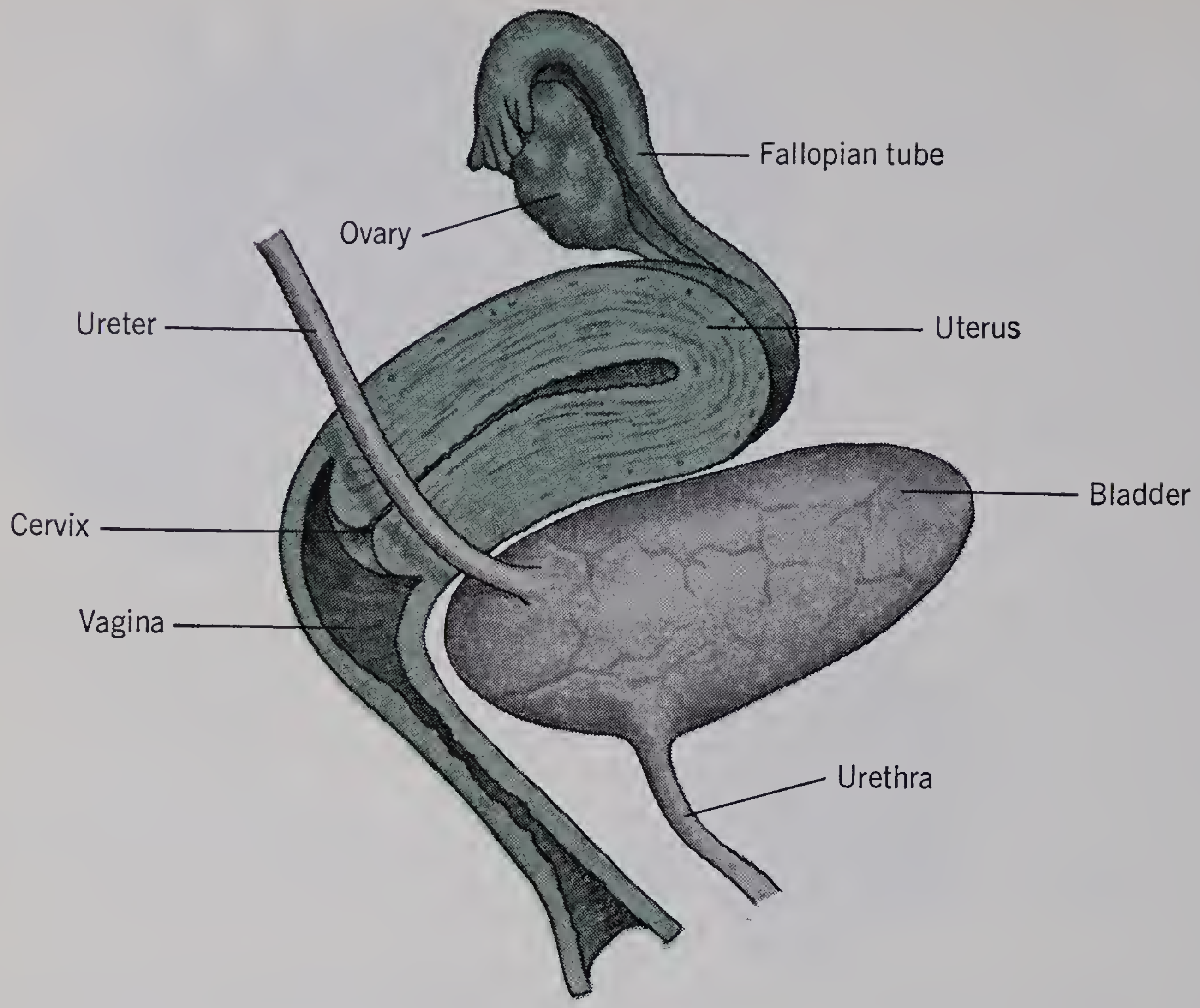
47-1 Diagram of the male reproductive system.

add their activating secretions to the sperm as they pass by. The fertilizing fluid consisting of sperm and fluids from the seminal vesicle, prostate gland, and Cowper's gland is called ***semen.*** In the male the urethra serves as a duct for the passage of semen and carries urine from the bladder for excretion.

Figure 47–2 contrasts sizes of the human ovum and sperm. The male gametes are very small and are motile. Each sperm is able to move by the beating of its flagellum. It has been estimated that 130 million motile sperm are necessary to insure fertilization of one egg. The human sperm consists of a head, neck, connecting piece, and tail. The head is a flattened oval-shaped part that is propelled by the lashing motion of the tail. It contains the haploid number of chromosomes. When the



47-2 This unusual photograph shows a human ovum at the time of fertilization. Although the ovum and sperm vary greatly in size and shape, they carry the same number of chromosomes. (L. B. Shettles, *Ovum Humanum,* Hafner Publishing Co., New York)



47-3 Diagram of the female reproductive system.

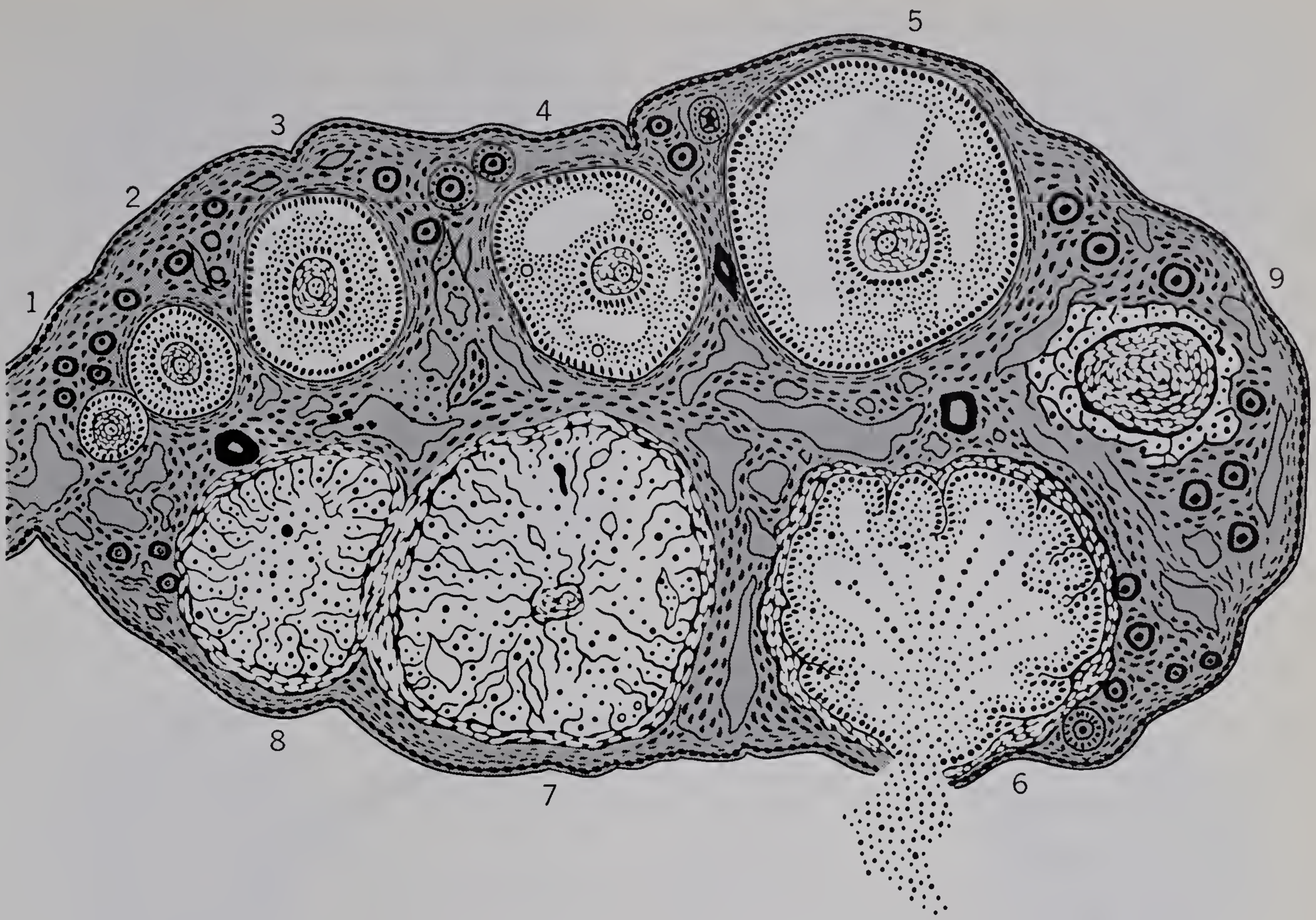
sperm penetrates an ovum at the time of fertilization, the tail separates. The head and connecting piece enter the ovum and the zygote is formed.

The female reproductive system. The paired ***ovaries*** of the female are located in the abdominal cavity on either side of the midline. They are about 1¼ inches long and ⅝ of an inch wide. The ovaries are not connected directly to the oviducts, or ***Fallopian tubes.*** When an ovum is released, the motion of ciliated cells lining the Fallopian tube causes it to be drawn into the tube. Then the ovum passes into the ***uterus,*** or womb.

The uterus is a hollow, thick-walled muscular organ. The mucous membrane lining the uterus contains small glands and many capillaries. If the ovum is not fertilized, it passes through the narrow neck of the uterus, called the ***cervix,*** and into the ***vagina,*** from which it is discharged.

The ovarian and uterine cycle. The development of the ovum and of the uterus are coordinated by hormones. The human ovaries usually produce only one egg during each 28-day cycle of activity. The mass of ovarian cells producing an ovum forms a ***follicle*** (Fig. 47–4). The cycle is controlled by a hormone called the *follicle-stimulating hormone,* or ***FSH,*** which is produced in the anterior lobe of the pituitary gland. As the egg reaches maturity, the follicle becomes filled with a fluid containing the hormone ***estrogen.*** Estrogen, as discussed in Chapter 46, brings about secondary sex characteristics in the female.

After the ovum has been discharged, the follicle becomes yellowish



47-4 Diagram of a section through the human ovary. Stages 1–5 show maturing of the ovum. Ovulation is taking place in stage 6, while in stages 7, 8, and 9 the corpus luteum is forming.

in color; it is now called the ***corpus luteum.*** The development of the corpus luteum is controlled by another hormone of the pituitary gland — the *luteinizing hormone,* or **LH.** The corpus luteum in turn produces another hormone, ***progesterone.*** The function of progesterone is to maintain the growth of the mucous lining of the uterus. If the ovum is not fertilized, however, the corpus luteum degenerates, progesterone is not produced, and the inside membrane of the uterus sloughs off. The breakdown and discharge of the soft uterine tissues and the unfertilized egg is called ***menstruation.*** Figure 47–5 shows the events of ovum production correlated with changes in the mucous membranes of the uterus.

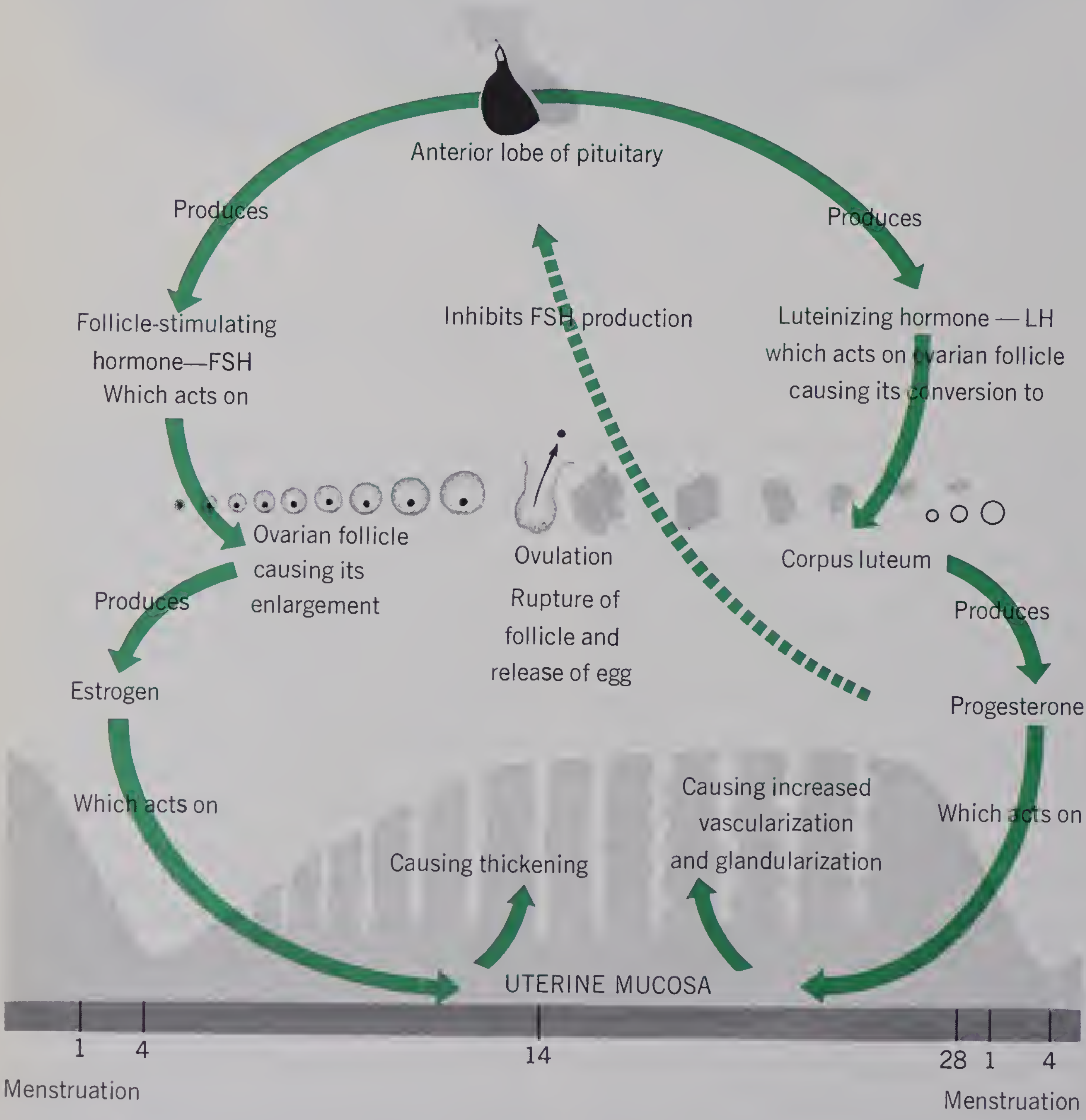
The uterine cycle consists of four recognizable stages: 1. *menstruation,* averaging about 5 days; 2. *the follicle stage,* occurring from the end of menstruation to the release of the ovum — about 10 to 14 days; 3. *ovulation,* the release of a mature ovum from the ovary; and 4. *the corpus luteum stage,* lasting from ovulation to menstruation — about 10 to 14 days.

Fertilization of the ovum. Immediately upon entrance of a sperm into the ovum, a membrane forms around the zygote (*zy*-goht). This is called the ***fertilization membrane,*** and its formation prevents other sperm from entering the ovum. Fertilization usually occurs in one of the Fallopian tubes, and it brings about several important changes. The corpus luteum of the ovary continues to develop and produce progesterone, which influences the uterus. The membrane of the uterus continues to thicken, and many small glands and capillaries form throughout the tissue in preparation for the zygote.

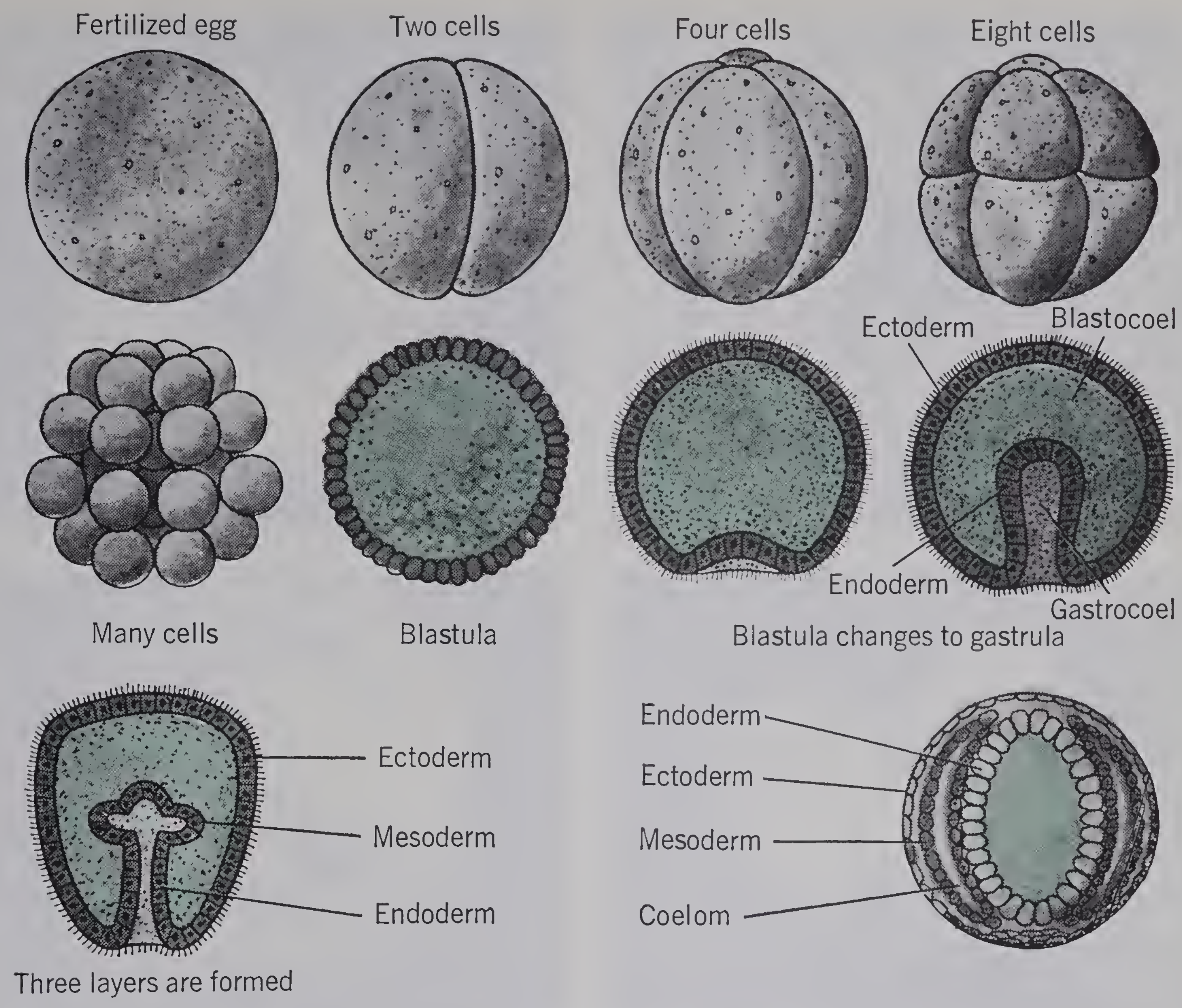
The zygote reaches the uterus in three to five days, and during this time it continues its growth. Following the re-establishment of the diploid number of chromosomes, the zygote begins a series of mitotic divisions, and in a few days it consists of a mass of cells.

Development of the zygote. The term *embryo* refers to a developing organism when its body form is not recognizable as a member of a certain species of animal. In the human being this stage lasts from six to eight weeks after fertilization. At the end of six weeks the embryo is about two-thirds of an inch long, but its growth rate increases and human characteristics become obvious. From this time until birth it is called a *fetus*.

Repeated division of the fertilized ovum results in a hollow sphere of cells


Anterior lobe of pituitary
Produces
Produces
Follicle-stimulating hormone—FSH Which acts on
Inhibits FSH production
Luteinizing hormone — LH which acts on ovarian follicle causing its conversion to
Ovarian follicle causing its enlargement
Ovulation
Rupture of follicle and release of egg
Corpus luteum
Produces
Produces
Estrogen
Progesterone
Which acts on
Causing thickening
Causing increased vascularization and glandularization
Which acts on
UTERINE MUCOSA
1
4
14
28
1
4
Menstruation
Menstruation

47-5 This diagram shows the relationship of the pituitary gland to the uterine cycle.

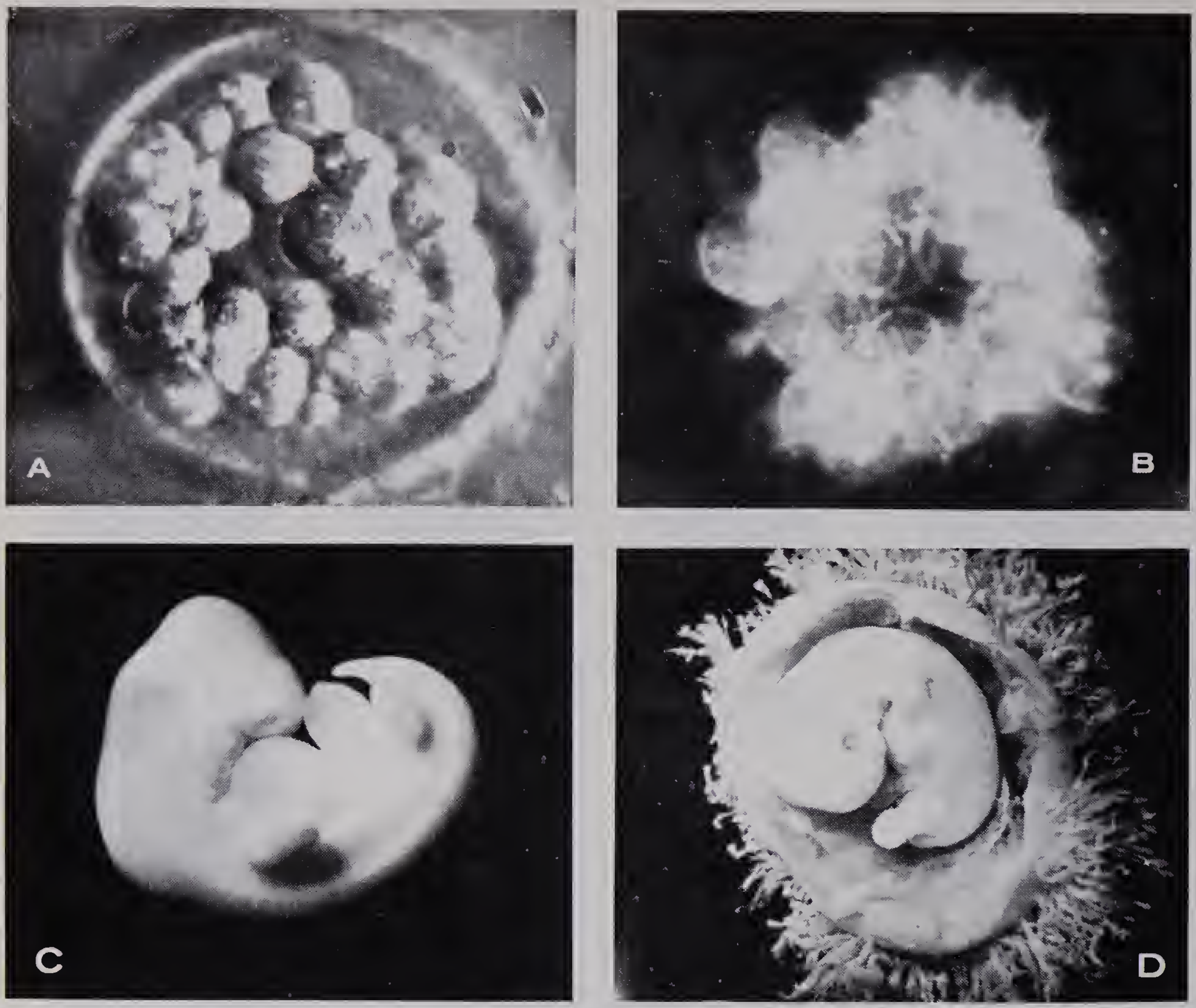

Fertilized egg
Two cells
Four cells
Eight cells
Ectoderm
Blastocoel
Endoderm
Gastrocoel
Many cells
Blastula
Blastula changes to gastrula
Ectoderm
Mesoderm
Endoderm
Three layers are formed
Endoderm
Ectoderm
Mesoderm
Coelom

47-6 Immediately following fertilization, cells divide repeatedly and finally form the blastula, which resembles a hollow ball. This continues its division until the gastrula is formed. In this stage the three germ layers that will give rise to tissues and organs differentiate. The beginnings of the body cavity, or coelum, may be seen in the final drawing.

known as a ***blastula*** (Fig. 47–6). One side of the blastula folds inward to form a shape called a ***gastrula.*** The edges of the gastrula then become fused together, and the embryo resembles a tube within a tube. In this stage the outer layer of cells is the *ectoderm* and the inner layer the *endoderm*. The space between the ectoderm and endoderm is the ***blastocoel*** (*blas*-to-seel), and the central cavity is the ***gastrocoel*** (*gas*-troh-seel). The gastrocoel develops into the digestive tract of the fetus.

As the embryo develops, cells of the endoderm begin to grow into the blastocoel and fill it. These cells form the *mesoderm*. The mesoderm then forms two layers of cells. The innermost layer adheres to the endoderm to form the wall of the digestive system, and the outermost layer forms part of the body wall. The space between the mesodermal layers forms the body cavity, or ***coelom*** (*see*-lom). The formation of a coelom permits the digestive tract to move freely.

The ectoderm, endoderm, and mesoderm are called the ***primary germ layers,*** as they form the various tissues and organs of the body. Structures of the body formed from the specific germ layers are summarized on page 655.



47-7 Growth of the embryo. A: 3 days old; B: 6 days old; C: 35 days old; D: 42 days old. (L. B. Shettles)

Attachment of the embryo. At the same time the embryo is passing down the Fallopian tube toward the uterus, a membrane forms around the mass of dividing cells. This is the first of several membranes that will form, and since it will not become part of the embryo itself, it is called an ***extraembryonic membrane.*** The first membrane, the *chorion* (*kor*-ee-on), forms many small fingerlike projections, the *chorionic villi.* Enzymes produced by the chorionic villi enable them to sink into the uterine membrane to make close contact with the capillaries and provide nourishment for the embryo.

Soon another extraembryonic membrane, the *amnion*, develops. The fluid in the cavity formed by the amnion protects the developing embryo from mechanical injury and keeps it moist. The *yolk sac* is the third extraembryonic membrane. In animals that hatch from eggs, this provides the food for the embryo. The human yolk sac is small and not significant. The *allantois* (a-*lant*-was) is the fourth extraembryonic membrane, and it is present in man for only a short time. In birds and reptiles this membrane serves as an embryonic lung.

Once the chorionic villi become embedded in the uterine wall, capillaries break down and form blood sinuses around the villi. There is no direct connection between the blood of the mother and the embryo, but food and

STRUCTURES FORMED FROM SPECIFIC PRIMITIVE GERM LAYERS

ECTODERM
- Skin and skin glands
- Hair
- Most cartilage
- Nervous system
- Pituitary gland
- Lining of mouth to the pharynx
- Part of lining of rectum
- Adrenal medulla

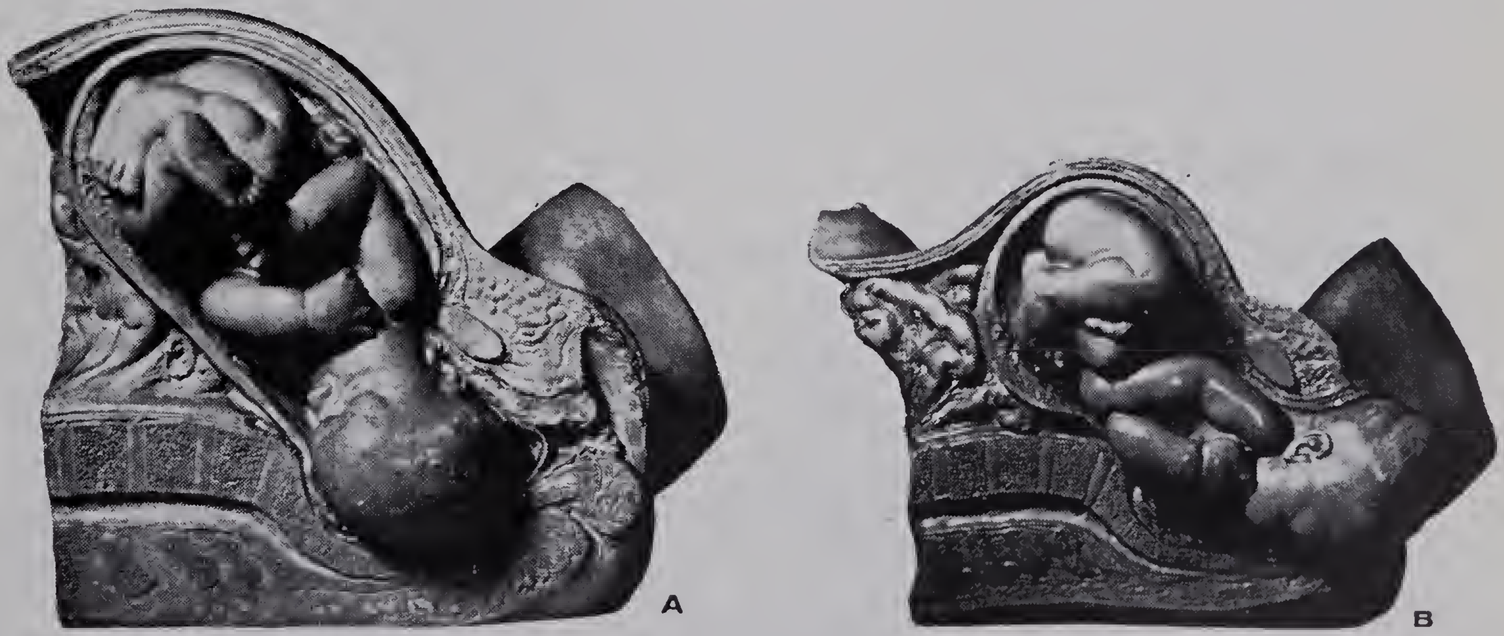
MESODERM
- Connective tissue
- Bone
- Most muscles
- Kidneys and ducts
- Gonads and ducts
- Blood, blood vessels, heart, and lymphatics

ENDODERM
- Lining of alimentary canal from pharynx to rectum
- Thyroid and parathyroids
- Trachea and lungs
- Bladder

waste exchange occurs by diffusion through the thin membranes. In the uterus the area of the chorionic villi and maternal blood supply forms the large thin membrane called the ***placenta.***

With growth the area that attached the embryo to the yolk sac and allantois lengthens to form the ***umbilical cord.*** Two umbilical arteries, one umbilical vein, and the allantoic duct connect the developing embryo to the placenta.

Birth of the child. The period of fetal development ends with the birth of the child approximately forty weeks after fertilization of the ovum. The smooth muscles of the uterus begin to contract, and when the membrane of the amnion breaks, the fluid is discharged through the vagina. Muscles of the cervix of the uterus and the vagina relax to increase the size of the opening. Further uterine contraction forces the child from the uterus. At this time the umbilical cord still attaches the baby to the placenta. To prevent loss of blood from the child through the umbilical vessels, the cord is tied and cut on the side of the pla-



47-8 Birth of the child. A: head is deep in the birth canal; B: head is beginning to emerge. Muscular contraction of the uterus expels the fetus during labor.

centa. The ***navel*** is a scar on the abdomen that marks the location where the umbilical cord attached to the fetus. Shortly after the child is born, the placenta and remains of the amnion, now called the afterbirth, are expelled.

Until the time of birth, the baby receives its nourishment and oxygen through the placenta. During development, movement of the thoracic muscles of the fetus draws fluid into the lungs, which aids in their expansion. The first cries of the infant remove the fluid and fill the lungs with air.

Another highly important change occurs at the time of birth. During fetal life, the blood does not circulate through the lungs. Instead, as blood leaves the right ventricle, it goes through a vessel called the ***ductus arteriosus***, which takes the blood to the aorta. In this way the lungs are short-circuited during the life of the fetus. At birth, however, the ductus arteriosus closes off and the blood flows through the pulmonary arteries to the lungs. This aids the lungs in their expansion as the baby begins to breathe for itself.

Occasionally the ductus arteriosus fails to close off completely. When this happens, all the blood does not get to the lungs. Thus the carbon dioxide content of the blood is higher than normal. This condition is one of the causes of blue babies. Often the vessel will close off naturally, but sometimes surgery has to be performed and the vessel is tied.

IN CONCLUSION

In placental animals, such as the human being, internal fertilization occurs. A balance of hormones controlling the development of the uterine wall prepares it to receive the embryo. By the time the zygote reaches the uterus it consists of many cells and an extraembryonic membrane that aids in attachment to the uterus. The total dependence of the fetus on the mother terminates when the offspring is born.

BIOLOGICALLY SPEAKING

- blastocoel
- blastula
- cervix
- coelom
- corpus luteum
- Cowper's gland
- ductus arteriosus
- embryo
- epididymis
- extraembryonic membrane
- Fallopian tube
- fertilization membrane
- fetus
- follicle
- FSH
- gastrula
- gastrocoel
- LH
- menstruation
- navel
- placenta
- primary germ layers
- progesterone
- prostate gland
- scrotum
- semen
- seminal vesicle
- seminiferous tubules
- umbilical cord
- uterus
- vagina
- vas deferens

QUESTIONS FOR REVIEW

1. Of what advantage is sexual reproduction to a species?
2. Describe the passage of sperm and the production of semen in the male reproductive system.
3. How does the quantity of sperm in the human being compare to the quantity of ova? Explain the significance of this variation.
4. Describe the passage of an ovum in the female reproductive system.
5. How do hormones influence the reproductive cycle in the female?
6. Name and define the four stages in the uterine cycle.
7. Describe the changes occurring in the formation of the embryo from the zygote.
8. Name and tell the function of the extraembryonic membranes.
9. Name several structures that are produced from the primary germ layers.
10. Name the components of the umbilical cord.
11. What important change occurs in the circulatory system after birth?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the importance of size and other structural differences in a human ovum and sperm.
2. Why must fertilization occur in a Fallopian tube prior to movement of the ovum into the uterus?
3. Explain why hormone imbalance that alters the normal function of the pituitary gland might result in interruption of ovarian function.
4. If an egg is fertilized, menstruation does not occur and the lining of the uterus is prepared for implanting of the embryo. Account for this in terms of hormone secretion.
5. Discuss the importance of the ductus arteriosis as a by-pass from the pulmonary circulation to the systemic circulation in a fetal heart.

RELATED READING

Books

Anthony, Catherine P. *Structure and Function of the Body*, 2nd Rev. Ed. C. V. Mosby Co., St. Louis. 1964

Asimov, Isaac. *The Human Body: Its Structure and Operation*. Houghton Mifflin Co., Boston. 1962

Cain, Arthur H. *The Cured Alcoholic: New Concepts in Alcoholism*. John C. Day, New York. 1964

Calahane, Dorothy and Payne, A. *The Great Nutrition Puzzle*. Charles Scribner's Sons, New York. 1956

Carlson, A. and Johnson, V. *The Machinery of the Body*, 5th Ed. University of Chicago Press, Chicago. 1961

Carrington, Richard. *A Million Years of Man*. World Publishing Co., Cleveland. 1963

Chandler, Asa C. *Introduction to Parasitology, with Special Reference to the Parasites of Man.* John Wiley and Sons, New York. 1949

Clark, W. E. LeGros. *History of the Primates: An Introduction to the Study of Fossil Man.* University of Chicago Press, Chicago. 1959

Clarke, Robin. *The Diversity of Man.* Roy Publishers, New York. 1964

Clymer, El. *The Case of the Missing Link.* Basic Books, Inc., New York. 1962

Dobzhansky, Theodosius. *Evolution, Genetics and Man.* John Wiley and Sons, Inc., New York. 1955

Faber, Doris. *The Miracle of Vitamins.* G. P. Putnam's Sons, New York. 1964

Haller, Albert von. *The Vitamin Hunters.* Chilton Book Div., New York. 1962

Hammond, Winifred. *Plants, Food and People.* The John Day Co., New York. 1964

Hyde, Margaret. *Your Brain — Master Computer.* McGraw-Hill Book Co., New York. 1964

Kimber, Diana C., et al. *Anatomy and Physiology,* 14th Ed. The Macmillan Co., New York. 1961

Lasker, Gabriel. *Human Evolution: Physical Anthropology and Origin of Man.* Holt, Rinehart and Winston, Inc., New York. 1963

Lehrman, Robert L. *The Long Road to Man.* Basic Books, Inc., New York. 1961

Life Nature Library. *Evolution.* Time, Inc., New York. 1964

McBain, W. N. and Johnson, R. C. *The Science of Ourselves.* Harper and Row, Publishers, New York. 1964

Osborn, Robert and Benton, Fred W. *Dying to Smoke.* Houghton, Mifflin Co., Boston. 1964.

Poole, Lynn. *Carbon 14.* McGraw-Hill Book Co. (Whittlesey House), New York. 1961

Riedman, Sarah R. *Our Hormones and How They Work.* Abelard-Schuman, Ltd., New York. 1956

Scheele, William E. *Prehistoric Man and the Primates.* The World Publishing Co., Cleveland. 1957

Schenk, Gustav. *The History of Man.* Chilton Company, Philadelphia. 1961

Schneider, Leo. *You and Your Cells.* Harcourt, Brace and World, Inc., New York. 1964

von Koenigswald, G. A. R. *The Evolution of Man.* University of Michigan Press, Ann Arbor. 1962

Wilson, Mitchell. *The Human Body: What It Is and How It Works.* Golden Press, New York. 1959

Articles

Deevey, Edward S. "The Human Population." *Scientific American,* September, 1960

Slaughter, F. G. "Heart Surgery." *Scientific American,* January, 1950

Surgenor, D. M. "Blood." *Scientific American,* February, 1954

UNIT EIGHT

ECOLOGICAL RELATIONSHIPS

Thus far we have analyzed a great variety of organisms as units of life. We have studied the substances composing them, the cells that make them up, their organs and their systems. Now we are ready to assemble these many organisms into living societies determined by the conditions they require for life. Our study now broadens to include the whole living world — its forests, grasslands, deserts, lakes, and oceans. In all of these communities, organisms with like requirements interact with conditions of the environment and with each other in a dynamic system. The exploration of these communities is one of the most fascinating areas of biology.

CHAPTER 48

INTRODUCTION TO ECOLOGY

The science of the environment. No plant or animal is independent of its environment. Organisms are products of their surroundings. These surroundings must provide conditions suitable for maintaining life and carrying on all the life activities. The study of the relationships of living things to their environment and to each other is the branch of biology known as ***ecology.*** The word means, literally, "the study of houses." The field or pond or forest in which a plant or animal lives out its days is in a very real sense its "house."

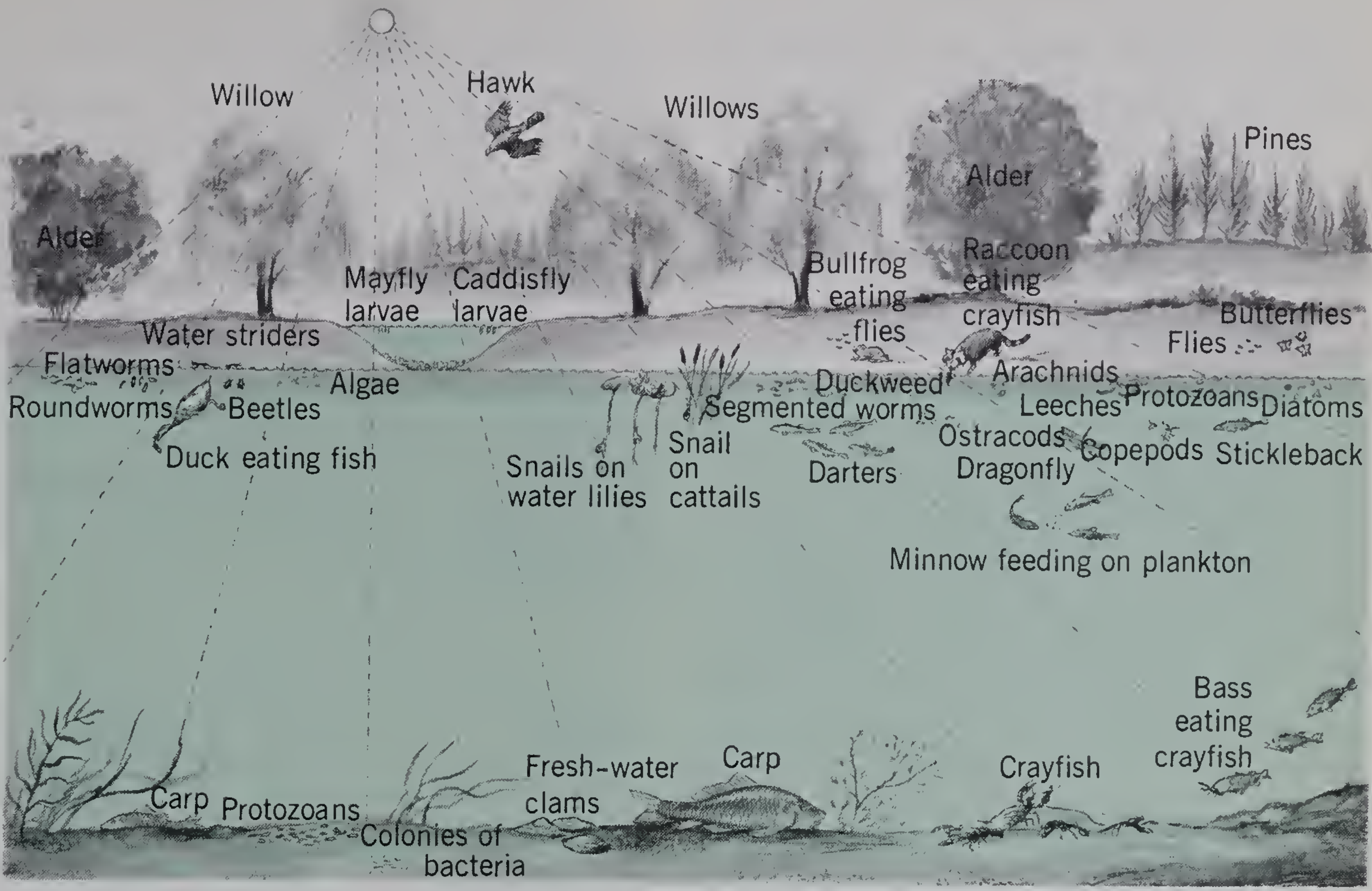
Ecologists work in every region of the earth — from equatorial forest to polar outpost and from ocean depths to mountaintop — studying the relationship of plants and animals to their environment. Any forest, field, pond, lake, or ocean is an outdoor laboratory to the ecologist.

The biosphere – the layer of life. The area in which life on our planet is possible is called the ***biosphere.*** Life exists only a few feet below the surface of the earth, on the surface, in the oceans and other bodies of water, and in the lower atmosphere. This comparatively thin layer of life is affected by many factors. The most important single factor affecting the biosphere is radiations from the sun. These enable green plants to manufacture food. Heat from the sun is vital to the existence of many organisms. It causes the evaporation of water, which in turn produces the earth's rainfall. This heat also creates the earth's winds. Although the entire biosphere may be considered one gigantic biological system, it is actually a complex series of systems within systems.

Ecosystems as units of the biosphere. Any stable environment in which living and nonliving things interact, and in which materials are used over and over again, is called an ***ecosystem.*** An ecosystem may be a jar with a fish, snail, water plants, water, and sand; or it may be a man in his spaceship. Forests, rivers, coral reefs, and ponds are examples of larger ecosystems.

The lake shown in Fig. 48–1 is an ecosystem. Although the diagram does not include all the organisms actually found in a lake, it does show typical ones. By becoming familiar with the various organisms in and around such a body of water, you will see how many factors affect the lake and its surrounding area.

The living organisms in an ecosystem are collectively referred to as the ***biotic community.*** All the organisms are not of equal importance in the community. Hydra, for example, may be plentiful on the water plants growing near the shore, but their contribution to the community would not be as significant as that of the crustaceans and in-


Hawk
Willow
Willows
Pines
Alder
Alder
Mayfly larvae
Caddisfly larvae
Bullfrog eating flies
Raccoon eating crayfish
Water striders
Butterflies
Flies
Flatworms
Algae
Duckweed
Arachnids
Roundworms
Beetles
Segmented worms
Leeches
Protozoans
Diatoms
Duck eating fish
Snails on water lilies
Snail on cattails
Darters
Ostracods
Dragonfly
Copepods
Stickleback
Minnow feeding on plankton
Bass eating crayfish
Carp
Protozoans
Colonies of bacteria
Fresh-water clams
Carp
Crayfish

48-1 A fresh-water lake is an example of an ecosystem, in which living and nonliving things interact.

sects on which some of the large animals feed.

Populations and their effects. A group of organisms of the same or related species in a given ecosystem is called a ***population.*** In discussing a population, we must identify the kinds of individuals and define their limits in the ecosystem. In a lake, for instance, we may refer to the plant-eating fish population in the summer of 1965. Even a greater number of different species would be involved if we referred to the insect population of the lake in the same summer.

The effects of various populations on one another will have more meaning if we consider the number of individuals. Populations vary in numbers of individuals from season to season or from year to year. An ecologist measures the changing populations by counting and recording individuals from a large area at various times. This measure of ***population density,*** then, is expressed as numbers of individuals in a definite area at a specific time. Density studies provide valuable information. For example, if we know the reasons for periodic fluctuations in the numbers and kinds of grasses on which cattle graze, we can use natural pastures without destroying them. All effective game laws are based on population studies. Game and fish populations are carefully harvested to insure future generations of men the pleasure of hunting and fishing.

How are density studies made? Obviously, it would not be practical to count all the clover plants in a field or on a hillside, or to count all the bass in a lake. Instead the ecologist selects several areas which are large enough for an accurate sample. Then he actually counts the individuals in the selected areas. Under natural conditions, organisms are not distributed evenly.

Such studies lead to new questions such as these: What factors are responsible for the uneven distribution? Why do populations vary from year to year?

The population of a given organism at any time depends on rates at which individuals are dying, being produced, or moving into or out of the area. If the reproductive and death rates of a trout population in a certain lake are equal, the trout population stays at a constant level. If studies over a period of years show a decline in the total trout population, there are reasons for the decline. If the ecologist can find the reasons, it may be possible to restore stability.

Levels of organization in the ecosystem. The following arrangement of biological organization will help you to visualize the relationships of the terms we have been discussing and shall use throughout our study of ecology.

Biosphere
|
Ecosystem
|
Biotic community
|
Populations
|
Organisms
|
Organ systems
|
Organs
|
Tissues
|
Cells
|
Molecules
|
Atoms

You can see that this list does not apply to all organisms. If you were considering the protozoans, for example, you would omit tissues, organs, and organ systems.

In discussing the various parts of the ecosystem, we have not mentioned the nonliving component. This is called the ***physical environment.*** As you will see, it has an important influence on living things. The ecosystem, therefore, can be more completely represented in the following way:

Ecosystem
Biotic community ⟷ Physical environment

Three kinds of relationships occur in an ecosystem: 1. the interactions in the biotic community; 2. the interaction between the biotic community and the physical environment; and 3. the interactions among the physical factors of the environment.

Interaction in the biotic community. By examining the ecosystem of the lake, you will be able to find many ways in which organisms are dependent on one another. How many organisms can you identify that compete for food, light, oxygen, or merely a place in which to grow? Competition within any one population is usually greater than that between different populations, as organisms of the same species have almost identical requirements. Male stickleback fish, for example, not only compete for food, but they also vie for a suitable nesting site and for a female. Cattails compete with one another for space, soil, and a suitable depth for growth. They would not compete as strongly with duckweed, for example. This small plant, floating on the surface of water, does not have the same requirements.

Interaction between the biotic community and the physical environment. Sunlight, soil, and temperature are some of the physical factors of the environment which constantly interact with the biotic community. As you know, all green plants require sunlight for photosynthesis. In a lake the plants are limited by the depths to which sunlight can penetrate. This depth depends on the clearness of the water. When this clearness is altered by a heavy growth of algae, or by mud stirred up from the bottom, the water may become turbid. In the clearest of lakes, light may penetrate to an average depth of 75 feet for the year.

The remains of dead plants that grow near the shore can alter the nature of the bottom. Over a period of years the area of a lake can be substantially reduced by the accumulation of dead shoreline plants. Organic acids and pigments from decomposing shoreline plants often affect the composition and color of the water in a lake or stream.

Water temperature may not be a significant factor to organisms living in deep lakes. At great depths, temperatures vary only slightly. But variations in daily and seasonal temperatures have a very great effect on the organisms living in shallow lakes or along the shore. These effects will be discussed further in the next chapter.

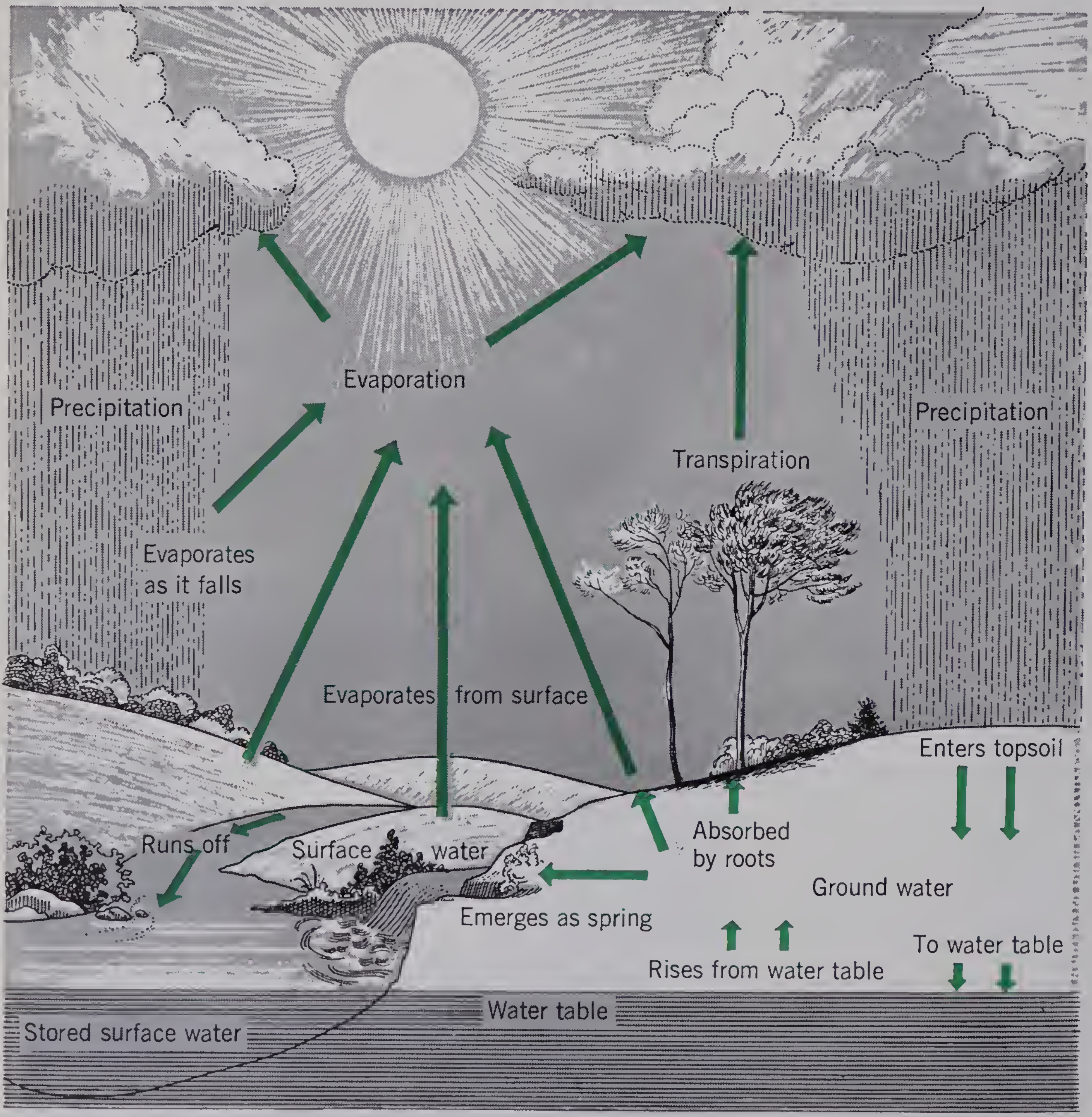
Another important factor influencing the distribution of plants and animals in a lake is man. Although man does not live in a lake, his influence over its biotic and physical environment should not be overlooked. Careless pollution of the water by industrial wastes or sewage can seriously alter both the balance and distribution of living things and the chemical nature of the water. Man, in satisfying his own interests, has turned rivers and streams into vast lakes, has turned rivers into open sewers, and has even altered coastlines. Many of the far-reaching effects of man's activities were not even considered until vast aquatic wastelands had been produced.

Interactions within the physical environment. The interactions within the physical environment may be temporary,

48-2 This lake was created as one result of an earthquake in Yellowstone National Park in 1962. This represents a permanent change in the physical environment. (U.S. Forest Service) as when a cloud cover reduces the light intensity. More permanent changes occur when a flood carries debris into a lake. Even the shape of the lake may be slightly altered by deposited materials. Some interactions in the physical environment may be permanent, as when an earthquake alters the course of the stream so that it bypasses the lake altogether. New springs may carry chemicals into the lake to alter the chemistry of the water. In many areas soda and sulfur springs may affect the chemical composition of the water.

The water cycle, a physical cycle Closely associated with the interrelationships of the biotic and physical environment, but exclusive to none, are the chemical and physical cycles. You have already learned much about the role of water, oxygen, carbon, and nitrogen in the maintenance of the living condition. Now let us see how they are returned to the atmosphere and become available again to organisms.

The *water cycle* is a continuous movement of water from the atmosphere to the earth and from the earth back to


Evaporation
Precipitation
Precipitation
Transpiration
Evaporates
as it falls
Evaporates from surface
Enters topsoil
Runs off
Surface water
Absorbed
by roots
Ground water
Emerges as spring
To water table
Rises from water table
Water table
Stored surface water

48-3 Trace the steps in the water cycle as shown in this diagram.

the atmosphere. The movement from the atmosphere to the earth is called ***precipitation;*** eventually this water returns to the atmosphere by ***evaporation*** (Fig. 48–3). When it rains, some of the water evaporates while falling and some evaporates quickly from the surface of the ground. Much of the rainwater runs along the surface of the ground and travels from rivulet to stream to river. This ***runoff water*** eventually reaches a pond, lake, or the ocean. Water evaporates constantly from the surfaces of this collection system. Large amounts of precipitation normally enter the soil to become ***ground water.*** This water may reach a pond, lake, or ocean through springs or underground streams; or it may move upward through the soil during dry periods and pass again into the atmosphere as water vapor. As warm air containing water vapor rises through the atmosphere, it cools. The vapor then condenses as droplets of water, forming clouds. The droplets collect to form drops, which fall from the clouds as rain. Snow is formed when the vapor condenses at a temperature below the freezing point of water.

Ground water and its movement. Topsoil acts as a sponge, receiving and holding water from precipitation. Some of this water moves downward into the subsoil and fills the spaces around the rock particles. The upper level of soil that is saturated with water is called the ***water table*** — the point at which water is standing in the ground. If the rainfall is heavy, most of the water may run off the surface instead of penetrating into the saturated topsoil.

The depth of the water table depends on the amount of precipitation, the condition of the soil surface for receiving water, the nature of the rock layers under the soil, and the proximity of large bodies of water. Where depressions occur, as in basins of lakes and ponds, the water table may be above the surface.

Plants do not wilt between rains because water moves from the water table up through the soil by capillary action. Much of this water is absorbed by roots and passed to the atmosphere during transpiration. Some of it reaches the surface of the soil, where it evaporates into the atmosphere. This movement of water upward from the water table is an important part of the water cycle. However, the largest proportion of the water enters the atmosphere by evaporation from the oceans and smaller bodies of water.

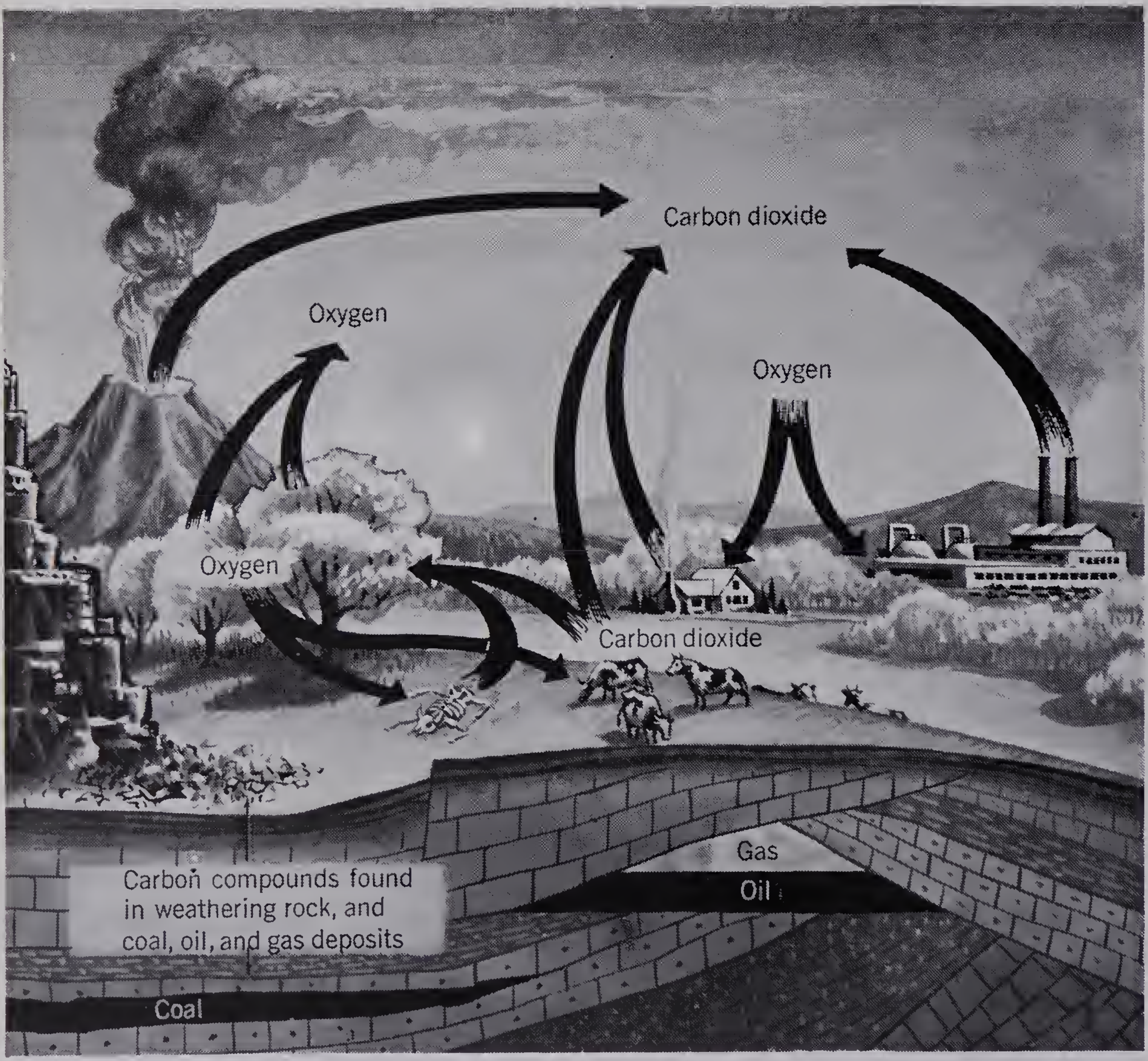
The role of living things in the water cycle. To a certain extent, both plants and animals are involved in the water cycle. Plants take in water through their roots by absorption, and give off water vapor from their leaves in transpiration. Animals are involved to the extent that they drink water and give off a certain amount of water vapor in exhalation. The percentage of total water that cycles through living things is small, however, compared to the amount that cycles through bodies of water, especially the oceans.

The carbon-oxygen cycle. Respiration and photosynthesis are the two basic life processes involved in the ***carbon-oxygen cycle.*** Land-dwelling organisms take oxygen directly from the atmosphere, while aquatic and marine organisms use oxygen that is dissolved in the water. The oxygen that is chemically united with hydrogen in water molecules is not available for respiration because organisms lack the ability to decompose water for this purpose.

During respiration, compounds containing carbon are oxidized to form carbon dioxide, and this gas is released to the environment.

During photosynthesis, green plants take water and carbon dioxide from the environment. In this process, as you recall, water molecules are decomposed so that their hydrogen atoms may be combined with carbon dioxide to form carbohydrates. Oxygen is released to the environment as a byproduct of photosynthesis. The atmosphere normally contains about 21 percent oxygen and 0.04 percent carbon dioxide. These percentages are fairly constant, indicating the efficiency of living things in maintaining the carbon-oxygen cycle.

Another portion of the carbon-oxygen cycle relates to the organic compounds synthesized by plants and animals from the carbohydrates produced in photosynthesis. Plants produce proteins and other protoplasm-forming substances. Animals that eat plants may synthesize other organic substances, and carnivorous animals in turn resynthesize these substances to


Carbon dioxide
Oxygen
Oxygen
Oxygen
Carbon dioxide
Gas
Oil
Carbon compounds found in weathering rock, and coal, oil, and gas deposits
Coal

48-4 The carbon-oxygen cycle. Carbon dioxide is used by green plants in photosynthesis and oxygen is released. Oxygen is used by animals and plants in respiration, and also in the burning of fuels. Carbon dioxide is released in both these processes, as well as in the process of decay.

suit their own needs. The carbon in these compounds is retained in the bodies of organisms until they die. It is then released as carbon dioxide when their remains decompose after death.

Smaller amounts of oxygen and carbon are involved in formation and decomposition of rocks and of mineral fuels such as coal and petroleum. These two elements are also involved in chemical changes when fuels are burned and when volcanoes erupt. However, the major contributing factors to the carbon-oxygen cycle are respiration and photosynthesis.

The nitrogen cycle. The ***nitrogen cycle*** involves green plants and several kinds of bacteria. It may or may not involve animals. As you read about the various steps in the nitrogen cycle in the next two paragraphs, follow them in the diagram shown in Fig. 48–5.

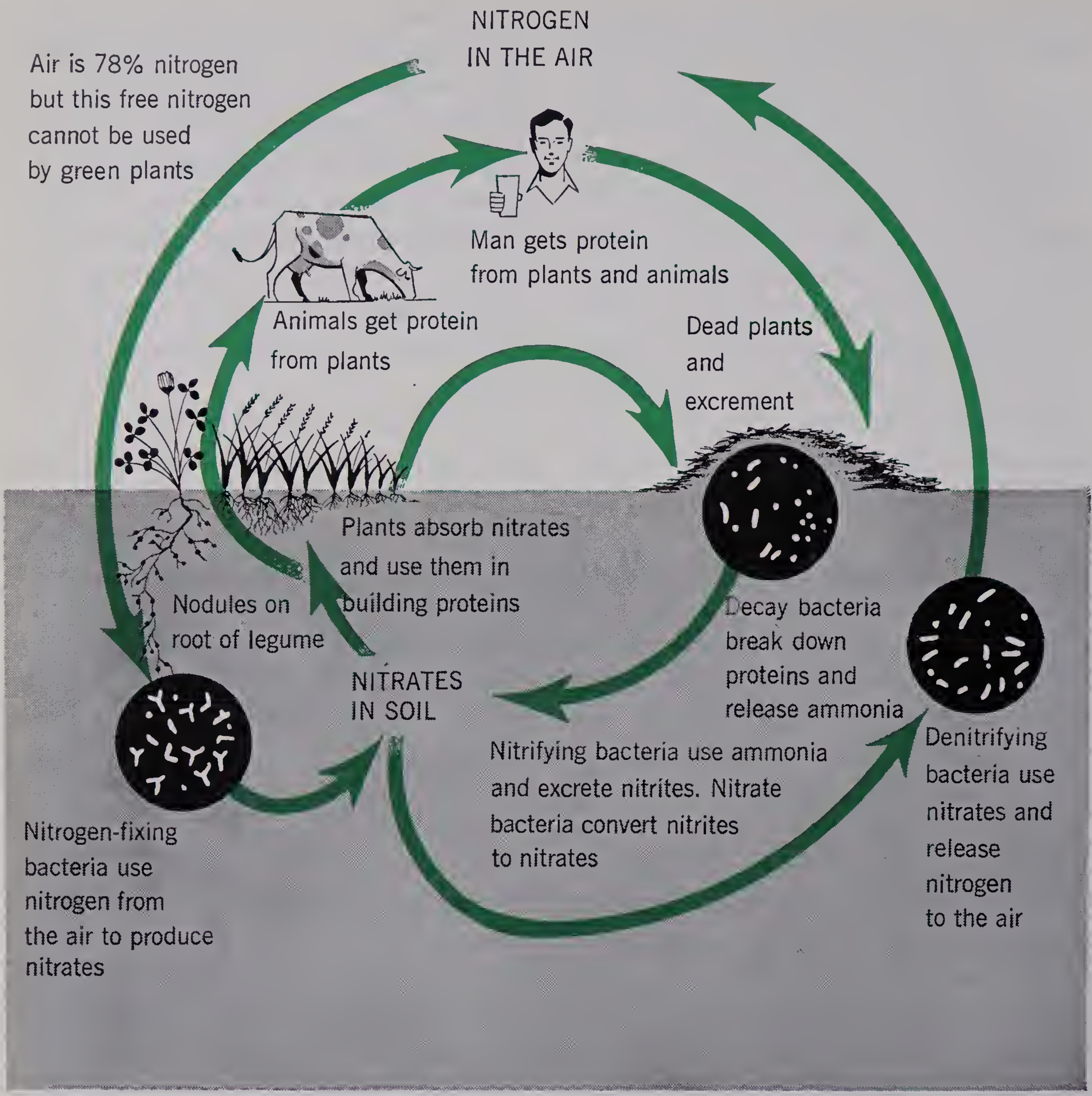
Let us begin with the green plant and the formation of protein. Its roots absorb ***nitrates,*** a group of soil minerals. These compounds contain nitrogen in chemical combination with oxygen and usually with sodium or potassium. In building proteins, the plant adds nitrogen from nitrates to the carbon, hydrogen, and oxygen which have been organized in an organic compound during photosynthesis. Sulfur and phosphorus may be added from other soil minerals.

Proteins are used in forming plant or animal protoplasm. This happens when one animal eats a plant or another animal. The chemical components of protein might change from plant to rabbit to fox, or from plant to beef steer to you. Each time an animal consumes protein in food, digestion separates its amino acids, which are then combined to form a protein characteristic of the organism in which it is formed.

However, not all of the protein consumed by an animal is converted into protoplasm. Some of it may be oxidized to produce energy. In this event, nitrogen compounds may be excreted by the animal. As you recall, this is one of the common functions of kidneys in higher animals. These excreted compounds may be further decomposed by bacterial action in the soil or water.

When an organism dies, decay by bacterial action begins. Nitrogen is released from the decaying protein in combination with hydrogen as ammonia. We refer to this part of the nitrogen cycle as ***ammonification.*** Other kinds of bacteria, living in the soil, oxidize ammonia and form ***nitrites,*** which cannot be absorbed by plant roots. Further oxidation by still other bacteria results in the formation of nitrates, the mineral compounds from which green plants receive their necessary nitrogen. We refer to the chemical process of nitrate formation by bacteria as ***nitrification.*** Thus, in starting with nitrates and ending with nitrates, we complete the nitrogen cycle.

The role of the atmosphere in the nitrogen cycle. As you probably know from your previous science courses, the atmosphere is composed of about 78 percent nitrogen. Is this pure nitrogen involved in any way in the nitrogen cycle? It is, but in a rather roundabout way. Atmospheric nitrogen cannot be used by green plants in their chemical activities. However, two groups of bacteria can oxidize free nitrogen and form nitrites and nitrates in the soil. One of these groups of bacteria lives in the soil. The other lives on the roots of clover, alfalfa, and other members of the legume family in a close relationship with the plant. The legume is the host, since the bacteria live within its tissues. These remarkable


NITROGEN IN THE AIR
Air is 78% nitrogen but this free nitrogen cannot be used by green plants
Man gets protein from plants and animals
Animals get protein from plants
Dead plants and excrement
Plants absorb nitrates and use them in building proteins
Nodules on root of legume
Decay bacteria break down proteins and release ammonia
NITRATES IN SOIL
Nitrifying bacteria use ammonia and excrete nitrites. Nitrate bacteria convert nitrites to nitrates
Denitrifying bacteria use nitrates and release nitrogen to the air
Nitrogen-fixing bacteria use nitrogen from the air to produce nitrates

48-5 The nitrogen cycle. In addition to the steps shown here, some free nitrogen in the air is changed to nitrates by lightning and is carried to the soil by rain or snow.

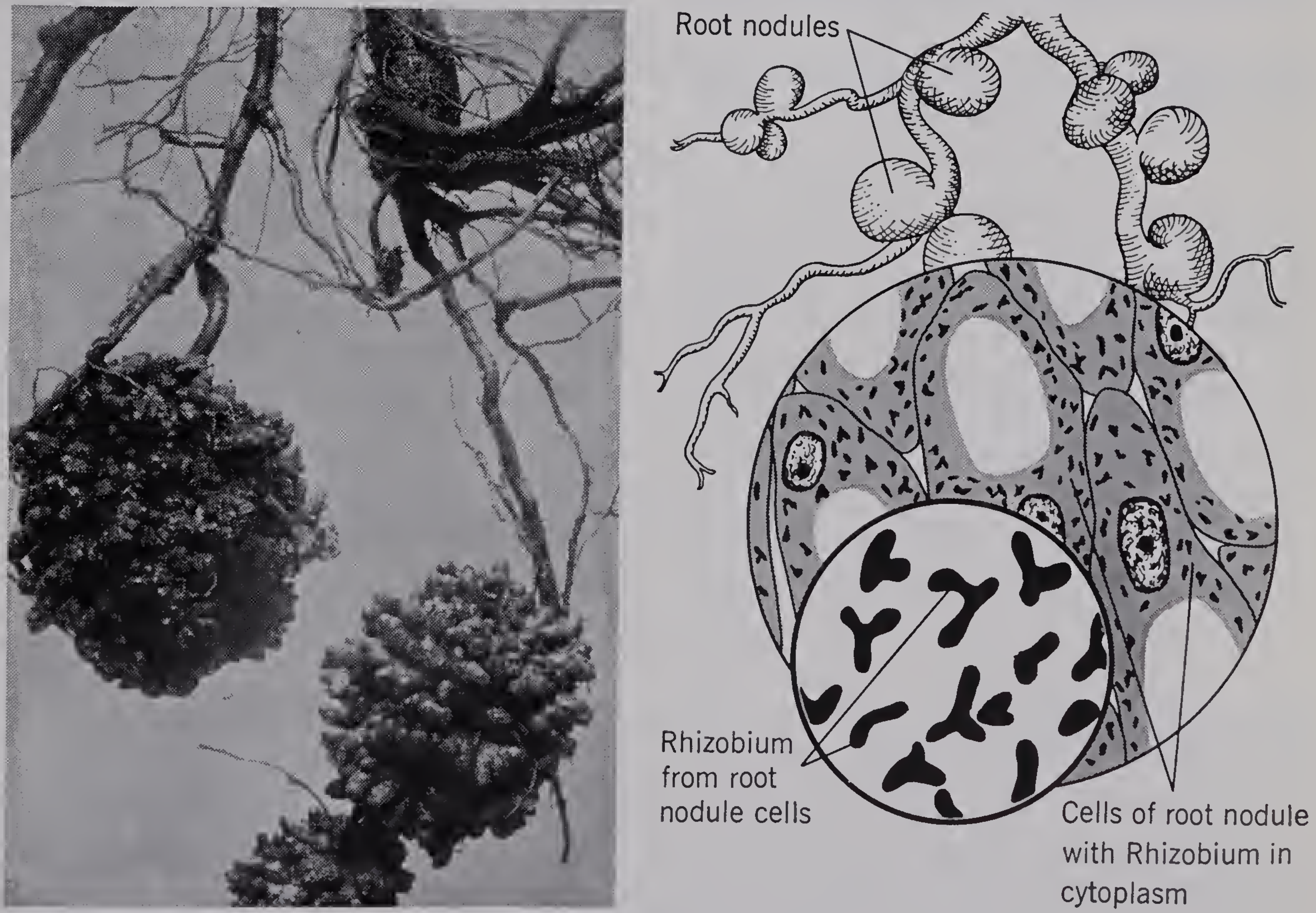
bacteria receive sugar from the host and use it in oxidizing free nitrogen to nitrates. The nitrates, formed within the cells of the roots of the host, can be absorbed and used in protein formation. Thus, the bacteria are of great benefit to the host plant. We refer to this important process as ***nitrogen fixation.***

Fortunately, legumes accumulate more than enough nitrates to meet their own requirements. The excess builds up the nitrogen content of the soil. When a farmer plants clover or alfalfa in a field as part of a crop rotation schedule, he knows he is building up his soil from almost unlimited supplies of atmospheric nitrogen. What he is actually doing is raising nitrogen-fixing bacteria. He will receive the greatest benefit if he plows the clover back into the soil at the end of the growing season.

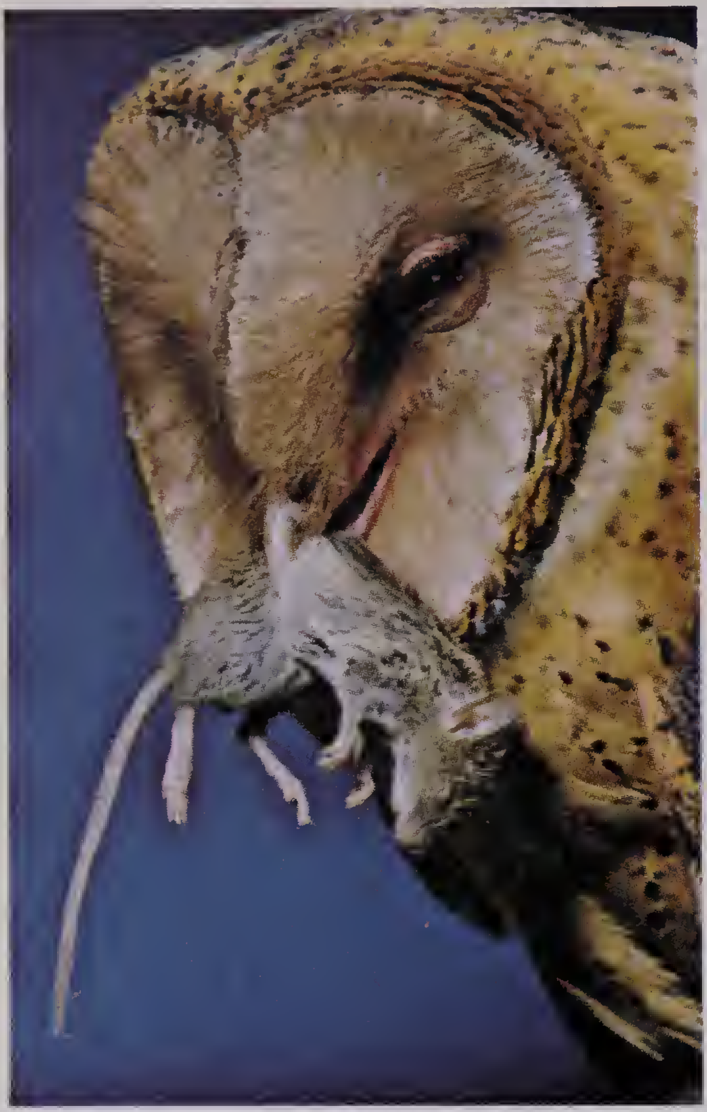
One phase of the nitrogen cycle, however, is unfavorable to agriculture. Certain bacteria liberate nitrogen by breaking down ammonia, nitrites, and nitrates in a process called ***denitrification.*** In this way some nitrogen may be lost from the soil. Fortunately, denitrification does not occur in well-drained, cultivated soil, since denitrifying bacteria are anaerobic. That is, they live in an environment that has little or no oxygen present. They thrive in soils that are water-logged, or packed so tightly that air cannot easily penetrate.

Biological balance in nature. The chemical cycles illustrate the interrelation of the life processes in plants and animals. Organisms are chemically associated with one another in a living society. Any biotic community is a complex of societies. It is composed of many kinds of plants and animals, living together in a very close association. If you study any plant and animal relationship closely, you can discover numerous ways in which they are dependent on one another. Some of the mutual dependence involves food supply and environmental conditions. Of great importance is the limiting effect organisms have on one another. Some forms of life may be more abundant than others, but no one kind of organism controls the community completely.

Let us consider the events in an open-field community. A meadow mouse is running along a pathway through the grasses in search of seeds. One might expect that by eating seed


Root nodules
Rhizobium from root nodule cells
Cells of root nodule with Rhizobium in cytoplasm

48-6 The nodules at the left, containing nitrogen-fixing bacteria, are found on clover. The diagram at the right is a detail of the bacteria themselves (*Rhizobium*). Of what benefit are the clover and the bacteria to each other?



48-7 The owl is a natural enemy of rodents, as it depends on them for its food supply. (Thornhill from National Audubon Society)

the mouse would reduce the next generation of grasses and other open-field plants. But since plants produce a far greater number of seeds than is needed for maintaining the plant population, plant numbers are not necessarily reduced. An owl swoops down and catches the mouse. The owl is one of the *natural enemies* of mice and other small mammals. We speak of it as a *predator* (*pred*-at-er) because it preys on other animals. Suppose there were no owls or other natural enemies of mice. Soon the mice would overrun the field. They might, then, actually reduce the numbers of grass plants and starve by virtue of their own numbers. This has happened many times in areas where animals have become too numerous.

In a forest, a field, a lowland marsh, a rocky meadow on a mountaintop — wherever life is found — there exists a close relationship between plant and animal and between prey and predator. Natural enemies play a vital part in maintaining the density of populations.

Keep in mind, however, that the relationships between organisms are not static. They may be affected by seasonal and annual fluctuations, or by disease or man. If the owl population should increase rapidly in a given area, for example, the rodent population would decrease. With the lowering of the number of rodents the grasses might increase in number and variety within the community. Many owls, however, would starve and the owl population would decrease. After a year or two the rodent population would build up to where it could support more owls, and the total animal-plant population would return to proportions similar to those existing before the "owl explosion."

IN CONCLUSION

To understand biology, we must know about the interrelationships of plants and animals and their environments. The study of these interrelationships is called ecology. The living world maintains a measure of stability by means of cycles. Constructive processes utilize simple inorganic compounds supplied by the soil and atmosphere. Equally important are the destructive processes that reduce complex organic matter to the simple compounds essential to future generations of living things. Thus, cycles continue age after age, and life continues.

Other conditions in nature have a direct and powerful influence on living things. Light, water, and temperature are critical factors in the life of plants. Plants in turn control the animal population. In the next chapter we shall consider, in more detail, the factors of the environment and their effects upon organisms.

BIOLOGICALLY SPEAKING

ammonification
biosphere
biotic community
carbon-oxygen cycle
denitrification
ecology
ecosystem
evaporation
ground water
natural enemies
nitrates
nitrification
nitrites
nitrogen cycle
nitrogen fixation
physical environment
population
population density
precipitation
predator
runoff water
water cycle
water table

QUESTIONS FOR REVIEW

1. What is the biosphere?
2. How would you go about making a density study?
3. What factors would you say determine the population of an organism at any time?
4. Would the list of biological organization apply to a sponge?
5. What does an ecologist mean when he speaks of interactions in the ecosystem?
6. What interactions occur between the biotic community and the physical environment?
7. What interactions occur among the physical environmental factors?
8. Describe the water cycle and discuss its importance.
9. Summarize the carbon-oxygen cycle and its value to living things.
10. Why is the nitrogen cycle so important in biology?

APPLYING PRINCIPLES AND CONCEPTS

1. Describe an ecosystem near your home.
2. Biologists sometimes speak of a "closed ecosystem." Explain why this might not be an accurate term.
3. Discuss possible reasons for annual variations of any specific population.
4. Discuss the methods an ecologist uses in determining the density of populations of organisms in an ecosystem.
5. Discuss the differences between the environment of the shore region of a lake and that of the deep-water bottom region

CHAPTER 49

THE HABITAT

The address and occupation of an organism. You are aware of the many general conditions under which plants and animals live. Conditions in a forest are quite different from those in an open field bordering it. The environment of a ravine or valley is unlike that of a hillside or mountaintop. Some of these differences are obvious; others are not. Still, each factor of an environment has a critical influence on the plants and animals that live there.

The ***habitat*** of an organism is the place where it lives. There are many habitats within the ecosystem of a lake. The habitat of the bullfrog is quite different from that of the bass, and yet both contribute to the complex structure of the ecosystem. In fact, a bass may occasionally eat a bullfrog if their habitats should happen to overlap. However, you would not go out to the middle of a lake to find a bullfrog.

The "address" of an organism is its habitat, but its ***niche*** is what might be called its "occupation." Within a biotic community there are many ways in which organisms can "earn a living." A lake, for example, may contain tiny suspended organisms of many species, called ***plankton.*** It is the niche of many small fishes to feed on these organisms. Larger fishes may occupy the same habitat as the small fishes, but are in a different niche because they feed on the small fishes. Different organisms that occupy the same niche are in competition with one another. For example, where they occur together, wolves and mountain lions occupy the same niche and are in competition for the animals on which they prey.

Limiting factors in the habitat. If an organism is to live in a certain habitat, it must be able to obtain the materials it needs for growth and reproduction. Anything that is essential to organisms and for which there is competition is called a ***limiting factor.*** Cattails growing along the shore of a lake, for example, require a marshy condition where the water is not too deep. In a lake, therefore, the area where the bottom is soft and the water is shallow is a limiting factor for cattails. They compete within that area and cannot live beyond it.

As you are probably becoming aware, the presence and continuing success of an organism may depend on a very complex and specific set of conditions. Just as a deficiency of any kind may limit the survival of an organism, so will an excess. An organism's ability to withstand a variety of environmental conditions is called its ***tolerance.*** A knowledge of the extremes of tolerance of organisms to various conditions will help us to understand why they live where they do. Many organisms, for example, live in estuaries where rivers carry fresh water into oceans or bays of salt water. The periodic rise and fall of tides and the variation in amounts of fresh water in the river during storms causes great fluctuation in the salt concentration of the water. The many kinds of worms, clams, oysters, fishes, and barnacles that live in such an area have a wide tolerance to water of varying salt concentration. Some of the deeper marine species of corals, sponges, sea urchins, and fishes would perish under such conditions, as they have a much narrower tolerance to changes in salt concentration.

As you have already seen, the habitats of organisms are governed by two sets of factors — physical and biotic. In order for an organism to survive in a particular habitat, both sets of factors must be such that they allow the organism to carry on its life processes. Thus geographic distribution of a species is governed by its limits of tolerance. We would expect to find a species concentrated in areas where the conditions are best for it. In their efforts to learn more about living things, biologists may deliberately subject organisms to a variety of conditions. Such tests reveal the limits of tolerance of organisms. Let's examine some of the important physical factors that limit the habitats of plants and animals.

Soil – a physical factor of the environment. Soil is more than just dirt that covers the earth. It is one of the most important factors of an environment. Careful examination shows that soil varies greatly in different localities. The plant and animal life it supports varies accordingly. Some soils are compact because they are composed mostly of *clay*, while others are loose because they contain mostly *sand*. The particles of *silt* are intermediate in size between those of clay and sand. *Loam* is a mixture of clay, sand, and organic matter. Sandy soils may support a pine forest in Michigan, New Jersey, Georgia, or eastern Texas. Heavy loam supports a beech and maple forest in Ohio and Indiana. Waterlogged soils of bogs and swamps provide ideal conditions for larch, white cedar, and cypress forests. The rocky, shallow soils of certain mountain slopes produce luxuriant forests of redwood, yellow pine, and spruce in our western states.

A *sour soil* is one that is acid; a *sweet soil* is alkaline. The degree of acidity or alkalinity in soil is an important factor in plant growth. For many plants, a neutral point midway between the acid and alkaline is best. Under cultivation soil tends to become more acid. To correct this condition, lime is often worked into the soil. Such plants as beets, spinach, lettuce, cauliflower, onions, peas, alfalfa, and clover do not grow well in acid soils. Plants like rhododendrons, azaleas, and blueberries, however, grow better in sour soil, and lime is harmful to them.

Salty and alkaline conditions of soil lower the productivity and value of much agricultural land in the United States. An estimated one fourth of our 29 million acres of irrigated land contains an excess of soluble salts of sodium, calcium, and magnesium. High concentrations of these elements reduce the rate at which plants absorb water, so that their growth is considerably retarded.

The character of a soil is always changing. In some places rocks are breaking down to form more soil. This breaking down is caused by the action of weather, by chemical disintegrations, and by plants growing on the rocks. In other places the mineral content of the soil is being depleted because of the

49-1 Temperature conditions in an alpine meadow such as this allow a spring growth of lupine, Indian paintbrush, and other flowers after the snows have melted. (Sumner from National Audubon Society)

quantities of salts removed by plants through their roots. Certain soils may be enriched through the decay of layers of vegetation, while other soils are becoming exhausted because of heavy crop production and failure to replace the lost minerals. Much useful farm land is ruined by bad soil care. As soils change, plants and animals must find other suitable habitats.

Temperature – an important controlling factor of the environment. In temperate regions of the earth, including most of North America, temperatures vary considerably. They range from narrow fluctuations between day and night to the much more extreme differences of summer and winter. Many animals do not maintain a constant body temperature. These are the cold-blooded, or ***poikilothermic*** (poy-kil-oh-*ther*-mik), animals. Their body temperature fluctuates with that of their environment. The birds and mammals maintain a fairly constant body temperature regardless of their surroundings. These are the warm-blooded, or ***homoiothermic*** (hoh-*moy*-uh-*ther*-mik), animals. Thus, as you might expect, the warm-blooded animals can extend their habitats over a wide range of temperatures.

On a cold morning a snake may crawl slowly out on a flat rock and lie in the sun. When its body temperature has increased, the snake becomes more active. Similarly, when the temperature is low, a butterfly may fan its wings for several minutes to warm up before flying. A meadow mouse, living in the same area as the snake and the butterfly, however, can wake up on a cold morning and dart about actively.

Any organism must be able to adjust to the slight variations between day and night. But seasonal variations between winter and summer present a much greater problem. Most trees and shrubs in temperate regions flourish through the fairly warm weather of spring, summer, and fall. Then they enter a ***dormant***, or inactive, period through the colder months. Leaves may fall, and sap may move to parts of the plant that are not injured by freezing. The leaves of the pine, spruce, and other evergreen trees remain throughout the winter, even though most activity in the plant has stopped. Nonwoody plants may die to the ground and then reappear in the spring from dormant roots, stems, or seeds.

Many birds of the Far North migrate into the northern regions of the United States during the winter months. Meanwhile, summer residents of these same areas have migrated into southern areas, even as far south as the tropics of South America.

Other animals may seek a protected cave or burrow under the ground where they become inactive or sleep during the cold of the winter. Some desert animals remain in their burrows during the heat of the day. A more detailed discussion of the adjustments of animals to seasonal and daily temperature variations will be found in the next chapter.

Water is essential to life. Probably no environmental factor is more important to living things than water. The habitats of plants and animals vary from a complete water environment to a sun-parched desert. The ways in which various plants and animals meet the universal need for water is always of interest to the biologist.

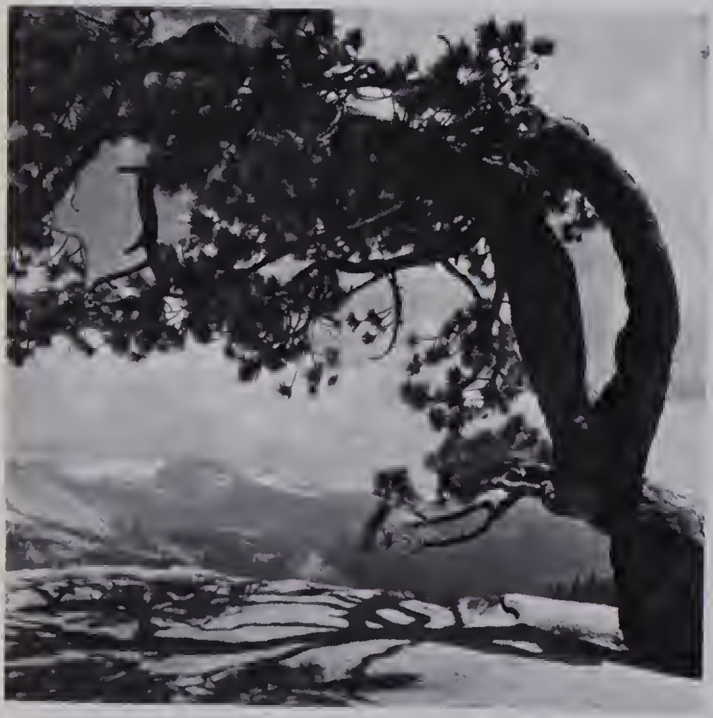
Oceans, lakes, rivers, streams, and ponds contain plants and animals that need a water environment. Water-dwelling organisms are said to be ***aquatic.*** Those living only in salt water are called ***marine.*** The bodies of such organisms are adapted to perform all their functions in water. Removed to land, even in the wettest surroundings, aquatic and marine organisms soon die. Land plants require less water than aquatic or marine forms. Rainfall is a major factor in controlling the lives of these ***terrestrial,*** or land-living, plants.

Ecologists classify plants that grow entirely or partially submerged in water as ***hydrophytes.*** Included among these plants are pond lilies, cattails, bulrushes, eelgrass, and cranberries. Plants that occupy neither extremely wet nor extremely dry surroundings are classified

49-2 Xerophytes, such as these cacti and other plants, make up the flora of a true desert. (Phoenix, Arizona, Chamber of Commerce) as ***mesophytes*** (*mez*-oh-fyts). The trees of the hardwood forests of the central and eastern states are mesophytes, as are most of the flowers and vegetables we cultivate in our gardens. In general mesophytes have well-developed roots and extensive leaf areas.

The driest environments — semideserts and true deserts — are occupied by ***xerophytes*** (*zer*-oh-fyts). These plants have extensive root systems for absorbing water and a greatly reduced leaf area to cut evaporation to the minimum. Cacti are examples of xerophytes whose leaves are reduced to spines and whose thick stems are adapted for water storage.

Light, an additional critical factor in the environment. As you already know, light is essential to all green plants in food-making. But we find certain plants and animals living normal lives in environments of total darkness. Blind fishes with undeveloped eyes live in underground streams and rivers in the Mammoth Cave of Kentucky and other dark places. Likewise deep-sea fishes live at depths to which light cannot penetrate. Many bacteria live without light, and are killed by long exposure to direct sunlight. Careful study of these organisms living in darkness, however, shows that all but a few species of bacteria depend indirectly on light for existence. They all require food and its stored energy for their activities. This food can be traced to the green plant and its food-making processes, which are, of course, dependent on light.



49-3 Note that the branches on this tree extend only in one direction. What factor is responsible for this? (Ewing Galloway)

Light conditions vary from place to place. Deep valleys, the floor of a forest, or the north side of a hill are places where plants and animals with low light requirements can thrive. Here we find snails, toads, and salamanders as well as ferns and mosses. Open fields, southern slopes, deserts, and other exposed places offer ideal situations for plants that need full sunlight. With these plants we find rabbits, ground hogs, coyotes, badgers, prairie dogs, ground squirrels, horned toads, and many other animals.

The atmosphere, a chemical storehouse. The air around us has an important direct effect on living things. With the exception of the anaerobic bacteria and a few other organisms, all living things must have free oxygen for life. This oxygen may be taken directly from the atmosphere or as a dissolved gas in water.

Deep-sea life has a greater oxygen problem than other forms of life. Since water receives its supply of oxygen from air, the oxygen content of water decreases with depth. The ocean is over 35,000 feet deep in the Mindanao Deep off the Philippine Islands. Yet deep-sea fishes thrive there only down to a mile below the surface.

Plants and animals that live in the soil are most abundant near the surface. The depth to which life can penetrate the soil is partly limited by food supply and certainly by oxygen supply.

Air movement, caused by fluctuations in barometric pressure, also has a direct influence on living things. Storms may destroy plants and drive animals to shelter. Air currents and winds have a much greater effect on life than most of us realize. Winds greatly increase the rate of evaporation of water. Plants and animals whose habitats are windy plains, prairies, and mountainous regions must not only withstand the wind, but must also survive the accompanying loss of water by evaporation. On mountains, high winds force trees to grow close to the ground and to form their branches only on the protected side (Fig. 49–3). Winds also cause a reduction in size of leaves and an increase in root systems.

The varied surroundings provided by land formations. The physical features of the earth, called ***topography,*** have a great influence on living things. Changes of the earth's topography are caused by such events as erosion, volcanic eruptions, earthquakes, and flooding. As the earth changes, so environments change. As a result, plants and animals must migrate to new and more favorable areas. They are then replaced by other organisms more suited to the conditions they left behind.

Nutritional relationships – important biotic factors. The way living things affect one another is equally as important as the effect of physical factors. Many of the biotic relationships involve food. The autotrophs, or "self-feeders," require only inorganic nutrients from the environment to synthesize organic compounds, so we call them food ***producers.*** In a lake these food producers are of three kinds: the emergent, rooted plants like cattails, and water lilies found near the shore; the submerged plants, like eelgrass and hornwort; and the suspended algae which form the *phytoplankton.* Microscopic examination of a few drops of pond or lake water usually reveals hundreds of one-celled algae.

At certain times of the year, the phytoplankton may increase so much that the lake water turns to a dark green color. At the time of such algal "blooms," the small crustaceans such as ostracods and copepods feed well. Since these organisms feed on plants, they are called ***herbivores*** (*er*-biv-ores). They are heterotrophs, or "other feeders," and are the first food ***consumers*** of the ecosystem. The energy synthesized and stored by phytoplankton is transferred to the protoplasm of the herbivores. The ***carnivores*** (*kar*-niv-ores), or flesh-eating animals, are sometimes divided into two groups: the *first-level carnivores,* which consume and use the energy of the herbivores; and the *second-level carnivores,*

49-4 Small crustaceans, like this copepod, are herbivores in a pond because they live on the phytoplankton. (Walter Dawn)

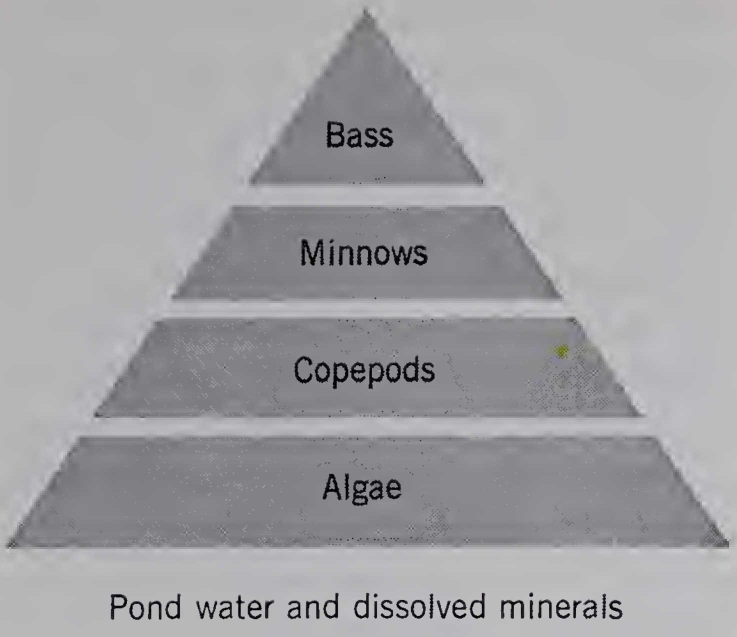
49-5 Scavengers such as snails occupy an important place in food chains. (Ross Hutchins)

which prey on the first-level carnivores. The copepods and ostracods in a lake are herbivores, while the minnows or the young fish that eat the copepods and ostracods are carnivores. Since young fishes may eat small minnows and herbivorous crustaceans, you can see that young fishes may be carnivores either of the first or second level, depending on the availability of food.

The *scavengers* feed on dead organisms. They are important in the cycling of chemicals and in the transfer of energy to the animals in the ecosystem that feed on them. These "garbage collectors" are represented in the lake by the crayfish and some snails. Many fishes are partial scavengers. The bacteria and yeasts are the ***decomposers*** in a lake. They break the tissues and excretions of organisms into simpler substances through the process of decay. Other bacteria present in the mud bottom of the lake and in the soil convert the simpler substances left by the decomposers into nitrogen compounds, which are in turn used by the plants. The bacteria that do this are called ***transformers***. Together, then, the decomposers and transformers return the nitrogen, phosphates, and other substances to the soil or water so that the plants can begin the cycle again. If decomposers did not exist, matter would not be available for reuse in the ecosystem.

Food chains in an ecosystem. The energy from the sun's radiation is converted into stored energy by the green plants. As the plants are consumed, much of the stored energy is released, but some of it is stored in the bodies of herbivores. When a carnivore consumes a herbivore, some of the stored energy is used and some is stored in the carnivore. Energy passes from the carnivores to the scavengers, decomposers, and transformers. It is important to remember, however, that not all the energy stored by a herbivore is stored by the carnivore. Much of it is used in vital processes like metabolism, locomotion, and reproduction. Only the excess energy is converted or stored.

We may examine the lake again for examples of energy transfer. Energy passes from the algae to the copepod to the minnow to the sunfish to the bass. If there is no predator of the bass, it is the top carnivore and may furnish the crayfish with food when it dies. The transfer of the sun's energy to a specific herbivore to a first-level carnivore to a second-level carnivore to a scavenger is called a ***food chain***. Food chains are sometimes long and complex. The chain in the lake could be extended by suggesting that a bullfrog may eat the crayfish and a raccoon may eat the bullfrog. Other food chains may also operate within the lake. The frog might eat a crayfish or a minnow and in turn be swallowed by a snake. If the conditions are right, the bass could con-



49-6 A pyramid based on the number of individuals in a pond.

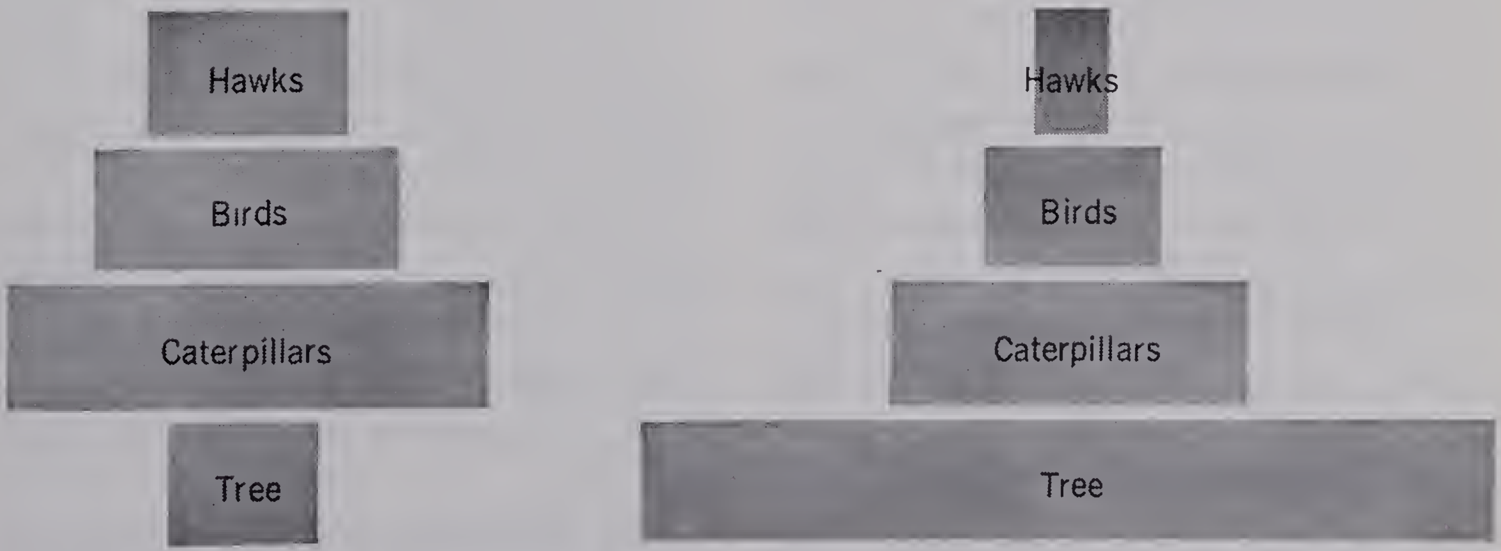
ceivably consume the snake. Now it appears that the biotic relationships are complicated by the integration of the food chains.

If you were to list every organism in the lake and draw arrows to indicate which organisms are used for food by others, your diagram would represent all the biotic relationships involving energy transfer. Since there are so many possibilities, this diagram would actually resemble a web more than a chain. For this reason food chains are sometimes called *food webs.*

Ecological pyramids. Food chains in an ecosystem are often represented as a pyramid, with the food producers forming the base and the top carnivore at the apex. Such a *food pyramid* can be made to represent an actual food chain by counting the numbers of individuals involved in each step of the chain. One such count of a bluegrass field revealed the following average per acre: 5,842,424 producers to 707,624 herbivorous invertebrates to 354,904 ants, spiders, and predatory beetles to 3 birds and moles.

Another way of studying food chains is to determine the weight in each step of the chain. This might produce a clearer picture of the biotic relationships, resulting in a more gradually sloping pyramid. Let's consider a sample pyramid involving a willow tree, caterpillars feeding on it, birds feeding on the caterpillars, and hawks feeding on the birds. In this pyramid one tree could support a number of caterpillars. Drawn on the basis of numbers, our pyramid would look like Fig. 49–7, left. However, if we were to represent this food chain by the weights of organisms, our pyramid would somewhat resemble Fig. 49–7, right.

Pyramids based on numbers of individuals or by weight indicate a condition found in the ecosystem at any particular moment. Remember, how-



49-7 Left: pyramid based on numbers; right: pyramid based on weight. The latter shows truer energy relationships.

ever, that conditions within the ecosystem are not static — they are always changing. The number and weight of a group of organisms does not depend on the number and weight of their food at any given time, but more on how quickly the food is being replenished.

By having a knowledge of food chains and pyramids, ecologists may be able to predict future events. Returning to our lake ecosystem, let us suppose conditions in the spring are favorable and an algal bloom results. The increase in the phytoplankton of the lake would be favorable to the organisms feeding on it. Many minnows, then, would be able to survive on the abundant food, whereas in less favorable years many would have died. These favorable conditions would suggest a larger gross weight for the bass population in the next year.

A knowledge of food pyramids may aid us in solving a human social problem. Can a population explosion such as we have in the world today continue indefinitely without a critical food shortage? In crowded regions, as in the Far East, people must live largely on vegetable diets. They cannot afford to use the food substance necessary to raise herbivores for meat, because the plant level of the pyramid supplies far more food from the available soil. Remember that each level of a food chain uses up some of the energy originally obtained from the sun. More food energy is available closer to the base level of the pyramid. By finding more ways to get nearer to the base of the pyramid, it may be possible to accommodate larger human populations.

Special nutritional relationships. In our study of food chains, most of the animals we have discussed are ***bulk feeders.*** That is, they consume tissues in bulk as whole organisms or parts of them. Most animals, including man, are bulk feeders. In another nutritional relationship the individuals live in direct association with each other. The relationship is called ***symbiosis,*** which means "living together." Biologists usually further divide symbiosis into three different kinds: 1. parasitism; 2. mutualism; and 3. commensalism. In ***parasitism,*** the parasite lives in or on another organism, called a host. The parasite benefits from this association, while the host is harmed. Tapeworms and lampreys are good examples of animal parasites. Other parasites include disease-causing bacteria, mildews, rusts, and smuts.

It is to the advantage of the parasite to keep the host alive. Death of the host results in loss of the parasite's habitat and food supply. Neither ticks, fleas, mosquitos, nor the fungus that causes athlete's foot kills the host. They take only enough nourishment to sustain themselves, to grow, and to reproduce. The biologically successful parasite is often a degenerate organism. However, it may possess structures lacking in free-living relatives. For instance, special hooks may hold it to the intestinal wall to prevent it from being swept away. It may have thick skin or cuticle to protect it from the corrosive action of the host's digestive juices. Many parasites have complicated methods of dispersal, requiring two or more hosts before reaching maturity.

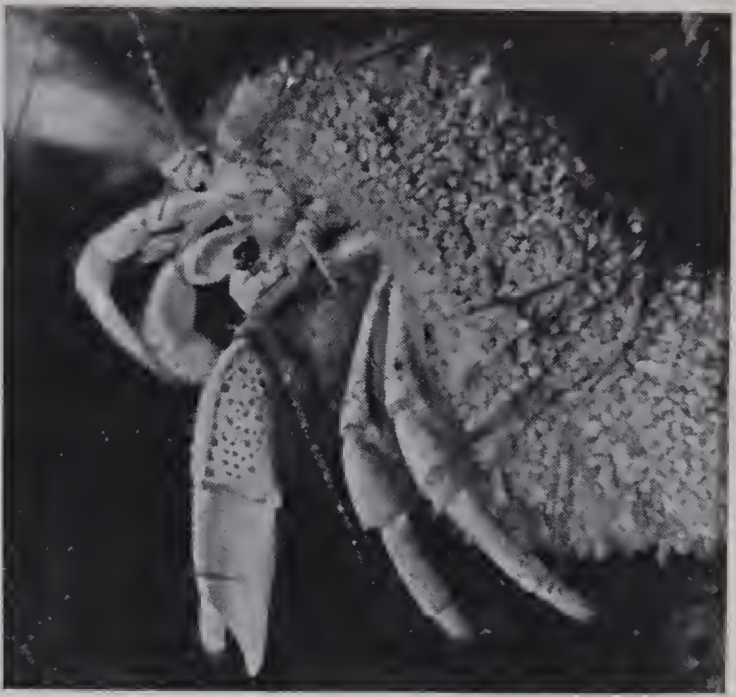
Every free-living organism appears to have its parasites, and many parasites have parasites of their own. In terms of numbers of individuals, there are more parasites than there are free-living organisms.

In ***mutualism,*** another form of symbiosis, two different kinds of organisms live together to the advantage of each.

In some instances the two organisms have become so dependent on each other that neither can live alone. Termites, for example, can chew and ingest the cellulose in wood, but they cannot digest it. The cellulose is digested by protists living in the termite's digestive tract. The termite is provided with a means of digestion, and the protist is given a place to live. The association of an alga and a fungus in lichens is another example of mutualism. The nonphotosynthetic fungus provides moisture and support for the alga, which in turn synthesizes food for the fungus and itself. Another well known example of mutualism is the relationship between the flowers that supply nectar to the insects that pollinate them. Many mammals are associated in a mutualistic relationship with specific birds that pick off and eat ticks.

In *commensalism* one of the partners is benefited while the other is neither benefited nor harmed. A good example of a commensal relationship is the remora and the shark. The remora is a small fish with a suction pad on top of its head. It attaches this pad to the lower side of a shark and feeds on scraps of the shark's food. The remora thus benefits, although the shark does not. But the shark is not harmed either. The term commensalism means, literally, "common table" or "messmates."

Another group of heterotrophs absorbs nutrients from dead tissues or products of organisms. These are the *saprophytes.* In this group are the bacteria that decompose plant and animal bodies; the molds that live on bread, fruit, leather, and other organic materials; the yeasts that ferment sugars; the fungi that live on dead trees, and many other organisms. While some saprophytes are destructive, others are very useful.



49-8 Here is a hermit crab with a colonial coelenterate living on its shell. What do biologists call such a relationship? (Walter Dawn)

Passive protection. Individual animals have some form of protection from bulk-food eaters. Claws, teeth, spines, stingers, pincers, and the ability to run fast are all used in defense. But many animals are able to survive because they can hide in their surroundings. Similarly, a predator uses concealment in hunting prey. Many animals would perish, either as prey or predator, if removed from their usual environment. A green katydid is nearly impossible to find among the green leaves of a lakeside tree, but if it should fall into the lake, it would be immediately vulnerable to birds, fishes, other insects, or frogs. The blending of an animal with its surroundings is a kind of camouflage. Many animals owe their existence to this protection.

Animal camouflage involves several principles. Sometimes the animal is colored or marked like its surroundings. We refer to such camouflage as *protective coloration.* The orange background and black stripes of the tiger blend almost perfectly with the grasses and shadows of its environment. A covey of

49-9 The yellow perch illustrates the principle of countershading. Its upper surface blends with the colors on the bottom of the lake or stream but its under surface is quite light so it blends with the reflection of the sky on water. (Chace from National Audubon Society)

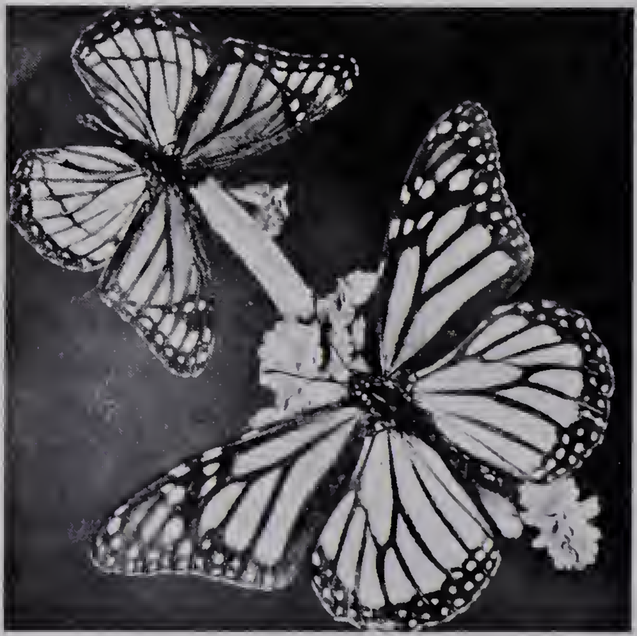
quail crouched in a thicket goes unnoticed until the individuals become frightened and fly into the air. The common tree frog has irregular markings of brown and ashy gray that blend with the bark of a tree. As you can see, protective coloration is a common adaptation for survival. Some animals blend so perfectly with their surroundings that only the most careful observer can discover them.

Fishes illustrate a slightly different principle. Darker colors on the upper side of the fish fade into light colors on the lower side. The coloring of the largemouth black bass is a good example of this principle, called ***countershading.*** The upper region of the body is greenish, blending with colors on the bottom of a lake or stream. The bass is nearly white on the lower side, so that it blends with the reflection of sky in the water. Thus the fish is protected from enemies above and below. You doubtless know how hard it is to see a fish in the water.

Still another principle of animal camouflage is illustrated when an animal resembles something in its environment. This is called ***protective resemblance.*** Several kinds of butterflies resemble brown leaves when their wings are folded. The walking stick, a relative of the grasshopper, actually looks like a stick with legs.

Mimicry is another type of protective resemblance. In mimicry, however, the animal looks like another animal rather than a part of its environment. Several kinds of defenseless flies resemble stinging insects. This gives them nearly the same protection as if they had stingers. Another example of mimicry is found in two butterflies, the viceroy and the monarch (Fig. 49–10). The monarch is the common orange and black butterfly seen around milkweed plants. The viceroy looks almost exactly like the monarch. The monarch has such an unpleasant taste that it is avoided by birds. The more palatable viceroy escapes because it looks so much like the unpalatable monarch.

In studying animal camouflage, we must keep in mind the principle of cause and effect. The animal does not blend with its surroundings *in order to*



49-10 Mimicry is represented by these butterflies. The one at the top is the viceroy while that on the bottom is a monarch. (Walter Dawn) *live.* Rather, it survives *because* it blends with its surroundings. Today, we see the result of many years of survival by those animals best adjusted to their surroundings. Through slight variations in form and color, certain individuals resembled their surroundings more than others. They had a better chance to survive and produce more of their kind. Variations appear slowly. It has taken many thousands of years for the animals we have just mentioned to develop. In the process, countless millions perished because they were not very well adapted to their environment.

IN CONCLUSION

All living things are interrelated with others and with the physical environment. Energy, originally from the sun, is transferred from one organism to another, and chemicals are cycled in the ecosystem. Soil, temperature, water, light, atmospheric conditions, and earth changes determine plant growth.

The producers, consumers, scavengers, and decomposers all have an important function in the transfer of energy and the cycling of inorganic compounds in a biotic community. On the basis of the manner in which organic nutrients are received from the environment, heterotrophs can be classified as symbionts, saprophytes, or bulk feeders.

In the next chapter we shall see the effect of periodic changes on organisms.

BIOLOGICALLY SPEAKING

aquatic
bulk feeders
carnivores
commensalism
consumers
countershading
decomposers
dormant
food chain
food pyramid
habitat
herbivores
homoiothermic
hydrophytes
limiting factor
marine
mesophytes
mimicry
mutualism
niche
parasitism
plankton
poikilothermic
producers
protective coloration
protective resemblance
saprophytes
scavengers
symbiosis
terrestrial
tolerance
topography
transformers
xerophytes

QUESTIONS FOR REVIEW

1. Explain the importance of plankton.
2. How does the tolerance of an organism for an environmental factor limit its distribution?
3. How does soil control the distribution of plants and animals?
4. Name several important controlling physical factors of the environment.
5. What is meant bv the terms "cold-blooded" and "warm-blooded"?

6. How do deciduous plants adjust to the freezing temperatures of winter?
7. How are environments classified according to the available water?
8. In what ways are plants adapted to live in environments of varying water content?
9. Although some organisms can live in total darkness, all are dependent on light. Explain.
10. In what environments is oxygen a limiting factor for organisms?
11. How does topography affect the distribution of living things?
12. Starting with the food producers, name and define the various types of organisms in a food chain.

APPLYING PRINCIPLES AND CONCEPTS

1. Choose some common organisms in your environment, and discuss possible limiting factors for each.
2. Discuss the importance of research on the limiting factors of specific organisms.
3. Does man's tolerance to a wide variety of conditions enable him to extend his habitat? What other factors are involved?
4. Discuss the survival value of the constant internal temperature condition found in some animals.
5. Give some possible reason why evergreens do not freeze and die when covered with snow during the freezing temperatures of winter.
6. Discuss the adaptations of plants growing in areas of reduced light.
7. Make a diagram of a food web that exists in your local area.

CHAPTER 50

PERIODIC CHANGES IN ENVIRONMENT

Alternating periods of activity. In the springtime people living in rural areas may waken to the sounds of hundreds of birds announcing the arrival of a new day. Attention is focused on the birds because of their songs. On the ground at the same time, snails, slugs, and sowbugs are making their way to protected spots where they will remain throughout the daylight hours. Some distance away, a meadow mouse narrowly escapes a diving hawk that had spotted it while soaring in the early morning sky above. If all goes well for the mouse, it will be safe for the remainder of the day. This was not the first escape for the little four-footed creature. Three hours earlier, in the dark of night, it had narrowly escaped the sharp talons of a barn owl. Each morning similar events occur wherever animals exist.

An organism that is active during the day is said to be ***diurnal*** (dy-*urn*-l), while one that is active at night is ***nocturnal*** (nok-*turn*-l). Each diurnal organism occupies a niche that may also be occupied by a nocturnal organism. The diurnal hawk's predatory niche, for example, is occupied by the owl during the night. Alternating periods of activity are called ***periodicity***, and when the periodicity is regular, it is said to be ***rhythmic***. Thus, the early bird getting its worm every morning shows rhythmic behavior. Although biologists have observed and studied rhythmic behavior in plants and animals for many years, there are still many challenging unsolved questions. Some animals have been described as having "internal clocks." What causes migrations of certain insects, birds, or mammals, and what causes hibernating animals to wake up?

Where rhythms have been observed and studied, light seems to be an important factor. It is not too surprising, then, to find rhythms based on daily, seasonal, and annual light variations. Rhythms that coincide with the changes in the moon phases have also been studied. However, as you will see, factors other than light are important in the control of regular activity of organisms. In the nocturnal white-footed mouse, daily behavior is not a simple matter of activity in the dark and rest in the daylight. When the animal is kept in constant darkness, its waking and sleeping periods continue as if it were exposed to normal periods of daylight and darkness. Thus, the animal has the capacity to "remember" its rhythm and is not entirely dependent on the external stimulus of light.

The daily rhythms. Similar environmental conditions are found in all forests, whether a lowland, hill top

50-1 The white-footed mouse is strictly a nocturnal animal and as such is a natural prey for owls. (Walter Dawn)

woods, or a lofty mountain forest. The tall trees provide areas of shade under which the shrub layer of the forest floor flourishes. In other areas, the sunny spaces provide meadows of various sizes where the grasses grow. Ferns cover the banks of streams. A summer morning may find the birds, chipmunks, and ground squirrels searching for food as the deer browse among the meadows. Before noon, however, the activity of the forest reduces.

As evening approaches, many of the diurnal animals renew their activity for a short time. Dragonflies and bats dart over streams and ponds searching for both diurnal and nocturnal insects available in this transition period. The sounds of the cicadas and birds gradually fade as the chirping crickets begin their activity. The foxes, raccoons, skunks, owls, and mountain lions begin their nocturnal search for food.

Although respiration in plants also occurs during the daylight hours, the photosynthetic manufacture of sugars proceeds rapidly during that time. In the darkness, when photosynthesis ceases, the manufactured sugars continue to be transported downward to storage tissues, and only respiration occurs. When plants bloom, the flowers may open and close at regular times of the day. The petals of the poppy flower, for example, open in the morning and close at night for several days. Many cacti bloom only at night and depend on nocturnal insects for pollination.

The desert environment, with its extreme temperature changes, brings about a sharper division between day and night activities. In the early morning hours, birds feed on insects and seeds, and jack rabbits come out of their burrows to look for food. The snakes, hawks, vultures, and ground squirrels are awake and active. Since the temperature may reach 170° F on

50-2 The night-blooming *Cereus* flowers only in the evening or at night. (Schneider from Black Star) the desert surface, noontime finds most of the desert creatures in the shade at the base of cacti, sagebrush, or creosote bushes. Many of them take to their cooler burrows, where the moisture in the air may be more than twice that of the atmosphere.

In the early evening many of these creatures again come out for a brief period. During the night, the poisonous Gila monster and the rattlesnake prey upon the many small nocturnal desert mammals. The bobcat, coyote, fox, and owl are some of the larger nocturnal desert carnivores.

In contrast to the desert are the polar regions, where the cold nights reveal very little activity. During the brief summer, most organisms are active throughout the prolonged daylight, but in the winter, only a few warm-blooded animals are active.

Farther from the poles, however, are the vast regions of treeless plains, where the ground remains frozen most of the year. For brief periods a shallow layer of earth at the surface thaws enough to allow lichens and some grasses to grow there. Among this plant life, a few warm-blooded animals such as the caribou, Arctic hare, fox, lemming, and ptarmigan spend the daylight hours obtaining food.

In equatorial regions the length of the day and night is nearly equal and the temperature is less variable. Light is, therefore, a more important factor in determining the periods of activity of the equatorial organisms. In the equatorial forests, nocturnal and diurnal animals are both very numerous.

Day-night rhythms are also found in the oceans, where periodic vertical migrations have been studied. Vast numbers of copepods and shrimp are found at night near the surface, where they are able to feed on the plankton. During the day these herbivores sink to a lower level and may be found 300 feet below the surface. Small carnivorous fishes follow the daily excursions of these plankton-feeders.

Seasonal community changes. Animals meet the problems of seasonal temperature changes in several ways. When the cold winter brings snow and freezing temperatures, an organism must be able to adjust or move away. Otherwise, it will die. The first freezing nights of winter take a heavy toll of insect life. Although the mourning cloak butterflies find winter protection in a hollow tree or crevice, most adult insects have completed their life cycle before the beginning of winter and are killed by the first frosts. Species survival through the winter is insured by other means. Many of the moths spend winter as pupae within silk-insulated cocoons. Grasshoppers, crickets, and cicadas lay eggs within the ground or in the bark of trees. Stoneflies, mayflies, and dragonflies spend the winter as nymphs in the water, sheltered beneath the frozen surface of a pond or stream.

The familiar honeybee finds protection in numbers. During the winter months, the bees feed on the honey that had been stored in the spring and summer. This supplies the bees with energy as they remain active in their hives during the winter months. The temperature within the hive may be as much as 75° F higher than that outside.

Animals like the eastern cottontail rabbit, the white-tailed deer, the cardinal, and the bluejay are permanent residents in their regions. During extremely cold weather, they find protection in woods and thickets; but when snow is on the ground, food-getting becomes a serious problem.

50-3 During the winter months many animals, like this chipmunk, hibernate. The animal's metabolism slows down markedly and does not accelerate until spring arrives. (Annan Photo Features)

Ground squirrels, chipmunks, woodchucks, and many reptiles and amphibians undergo true ***hibernation*** during cold weather. The rate of body metabolism drops greatly. Heart action and respiration decrease, and the animal loses consciousness. Greatly reduced activity lowers energy requirements to the minimum. An animal undergoing true hibernation cannot resume activity until the temperature of the environment increases and the body processes speed up.

Some animals that remain in a region during unfavorable periods may enter a state of dormancy. That is, they reduce their life activities to the minimum necessary for survival. The bear finds a hollow log, a cave, or some other protected location and lives on stored fat during his ***winter sleep.*** Although its activities slow down, a normal body temperature is maintained, and the bear can be awakened. It may even leave its shelter on a mild winter day. The skunk, raccoon, and opossum undergo a similar winter sleep.

During hot weather many animals enter a period of dormancy sometimes referred to as summer hibernation. The biological term for this is ***estivation.*** A frog may estivate in the cool mud at the bottom of a pond. The box turtle often escapes the heat by burying itself in a pile of leaves. The period of estivation may be several days or several weeks. The gopher tortoise of the southeastern states finds protection deep in a burrow in the ground. The California ground squirrel sleeps in its burrow, thus reducing both its food and water needs.

Many animals migrate to warmer regions when winter comes. We usually associate ***migration*** with birds, but some mammals also show the tendency to migrate. These seasonal journeys may cover thousands of miles. Some mammals make a migratory journey because of seasonal changes in the food supply. Others migrate to a more favorable climate regardless of food supply. Still others make seasonal journeys to regions where they can produce their young under the most favorable conditions.

The bighorn sheep spends its summers in the high meadows near the summits of the Rocky Mountains. As winter approaches, it moves down into the protection of the forests on the mountain slopes. Through the summer months, herds of Olympic elk browse in the high altitude of the mountains on the Olympic Peninsula. During the winter these herds move to the more protected mountain valleys and nearby plains. With the coming of spring, the herds move back up the slopes in long, single-file processions.

Among the most remarkable migrations is that of the fur seal. During the winter, females, young males, and

50-4 These monarch butterflies spend the winter in a pine grove in California after migrating from Canada. (Shropshire Camera Exchange)

pups roam the waters of the Pacific Ocean to as far south as California. The older males winter in the cold waters near Alaska and the Aleutian Islands. With the approach of the breeding season in the spring, the males migrate to the Pribilof Islands, north of the Aleutians. The males arrive several weeks before the females and battle for a territory. The females and young seals start their long journey of 3,000 miles or more to the Pribilofs in the spring and arrive in June. A herd of 50 or more females gathers around each male. Pups from the past year's breeding are born almost immediately and within a week, breeding occurs again. After this the seals migrate southward.

A butterfly migration. The monarch, or milkweed butterfly, one of the strongest insect fliers, makes a remarkable seasonal journey. In later summer these butterflies gather by the thousands in northern Canada and begin a long flight southward. Some of them travel to the Gulf states to spend the winter, but their habits there have not as yet been studied. Others travel a southern route along the Pacific Coast. Some time between the middle of October and the first of November, tens of thousands of these insects arrive on the Monterey Peninsula in the small town of Pacific Grove, California. Here they seek shelter in a specific grove of pines. The monarchs hang by their legs from the branches and needles in such large numbers that the trees appear to be solid brown (Fig. 50–4). They stay there in a state of semihibernation until the winter is over. On warm sunny days throughout the fall and winter, many will be seen flying about local gardens gathering nectar.

In March the monarchs fly out over Monterey Bay to begin their northward flight. As they fly north, they lay eggs on milkweed plants. It is unlikely that any of the travelers ever reach their northern home, because many die after the eggs are laid. However, after the eggs hatch, the larvae pupate, the young butterflies emerge, and the trip northward is continued. These new butterflies also lay eggs on milkweed as they progress.

By late summer the monarchs begin amassing for their southward journey to the same locality and the same trees where their ancestors of two generations past spent the winter. Although we attribute the monarch's behavior to instinct, the factors causing the migrations and the ability of these butterflies to find their way are not well understood.

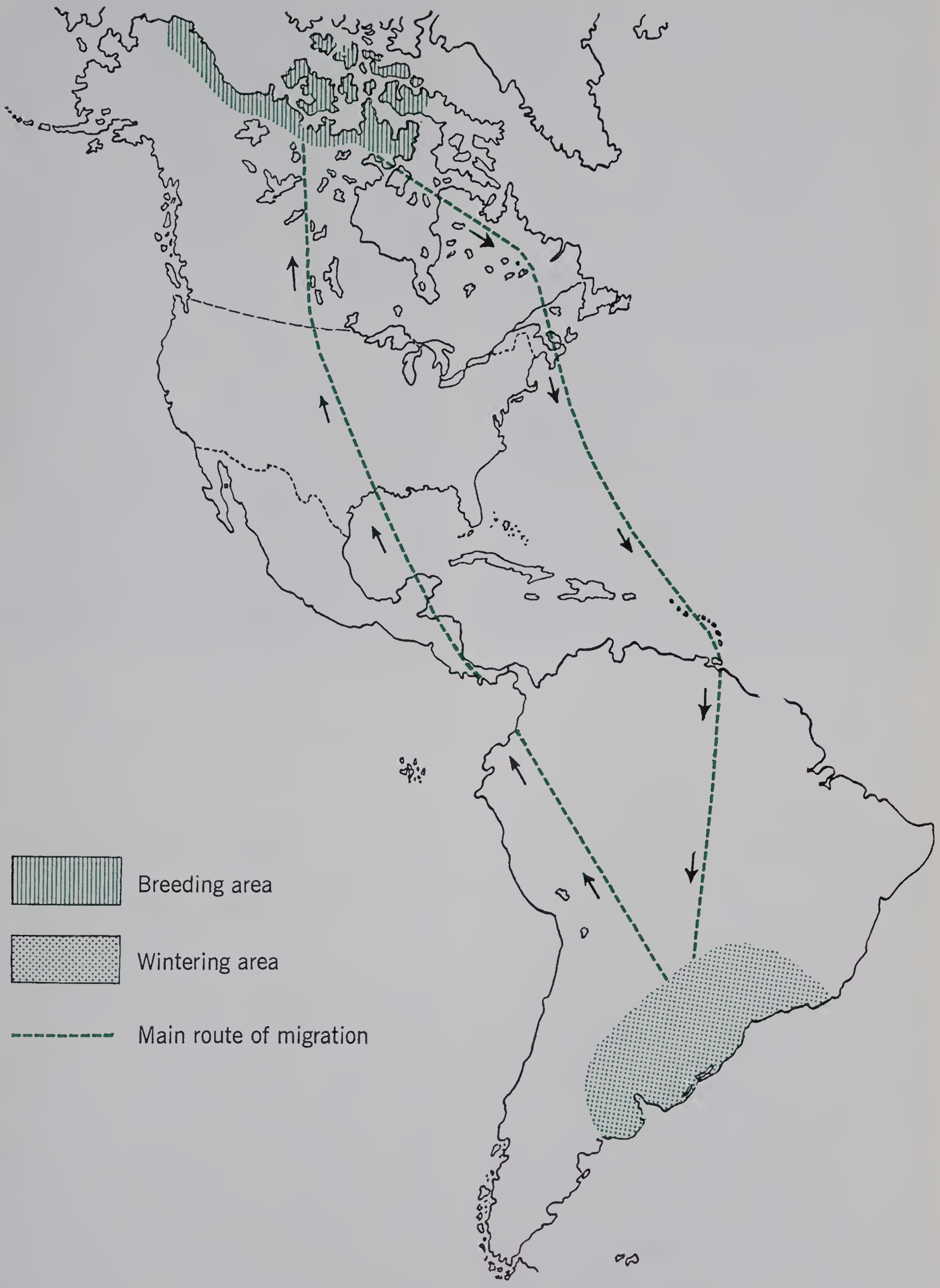
Bird migration. One of the most interesting instincts of birds is that which controls their migration. Many birds fly long distances in the spring, then nest and raise their young in a new home. They return to warmer climates in the fall. Migration may be prompted by food needs, climatic changes, or breeding habits. It is difficult to determine why some species leave abundant food and warmth in the tropics to migrate to breeding grounds in the Far North. Much more easily explained is the southward migration of insect-eaters when cold weather kills their prey, and the southward flight of water birds before the ponds and lakes freeze over. It is logical, too, that fruit- and seed-eaters would tend to follow their food supplies.

Some birds make their migratory flights at night and some during the day, depending on the species. Perhaps you are familiar with the night flights of geese during the spring and autumn, when they become confused by the lights of a city and circle about, honking noisily. The daylight flights of thousands of red-winged blackbirds and grackles are familiar sights during spring and fall.

While many birds migrate slowly, feeding along the way and averaging only 20 to 30 miles a day, others are marvels of speed and endurance. The ruddy turnstone travels each autumn from Alaska to Hawaii in a single flight, and the golden plover travels from Canada to South America, more than 8,000 miles as you can see from the map in Fig. 50–5.

Migratory routes. We do not know much about the instinct that governs the time and route of migration. Any given species follows the same route year after year and may be expected to arrive at a certain point within a few weeks of the same time each season, depending on the weather. As though to vary the scenery, certain species travel northward along one route and return by an entirely different route. How do they know the way? Keen sight may help, but not over water or through dark nights and fogs. Even the memory of old birds that have made the flight before cannot account for the unescorted flights of young birds. Biologists have now determined that the sun guides birds on their daylight flights. There is also good indication that birds are able to allow for the variations in position of the sun in different seasons and in different latitudes. This finding does not infer that birds understand intellectually their position in relation to the sun.

What about the migratory flights of birds at night? Recent studies of night flights reveal even more amazing possibilities. Birds seem to be directed by the position of the stars. Investigators in Europe have used caged birds in a planetarium in which star patterns of different seasons and various places in the earth can be projected on a dome representing the heavens. They have found that certain birds, including warblers, make a definite response to the po-


Breeding area
Wintering area
Main route of migration

50-5 The golden plover travels more than 8,000 miles in a single migratory flight. It breeds in northern Canada during the summer, flying in the fall to South America, where it spends the winter before returning north.

sition of stars during the normal season for migration. Under a fall star pattern, they face toward the winter migratory home in their cages. Under a spring pattern, they face toward the summer home.

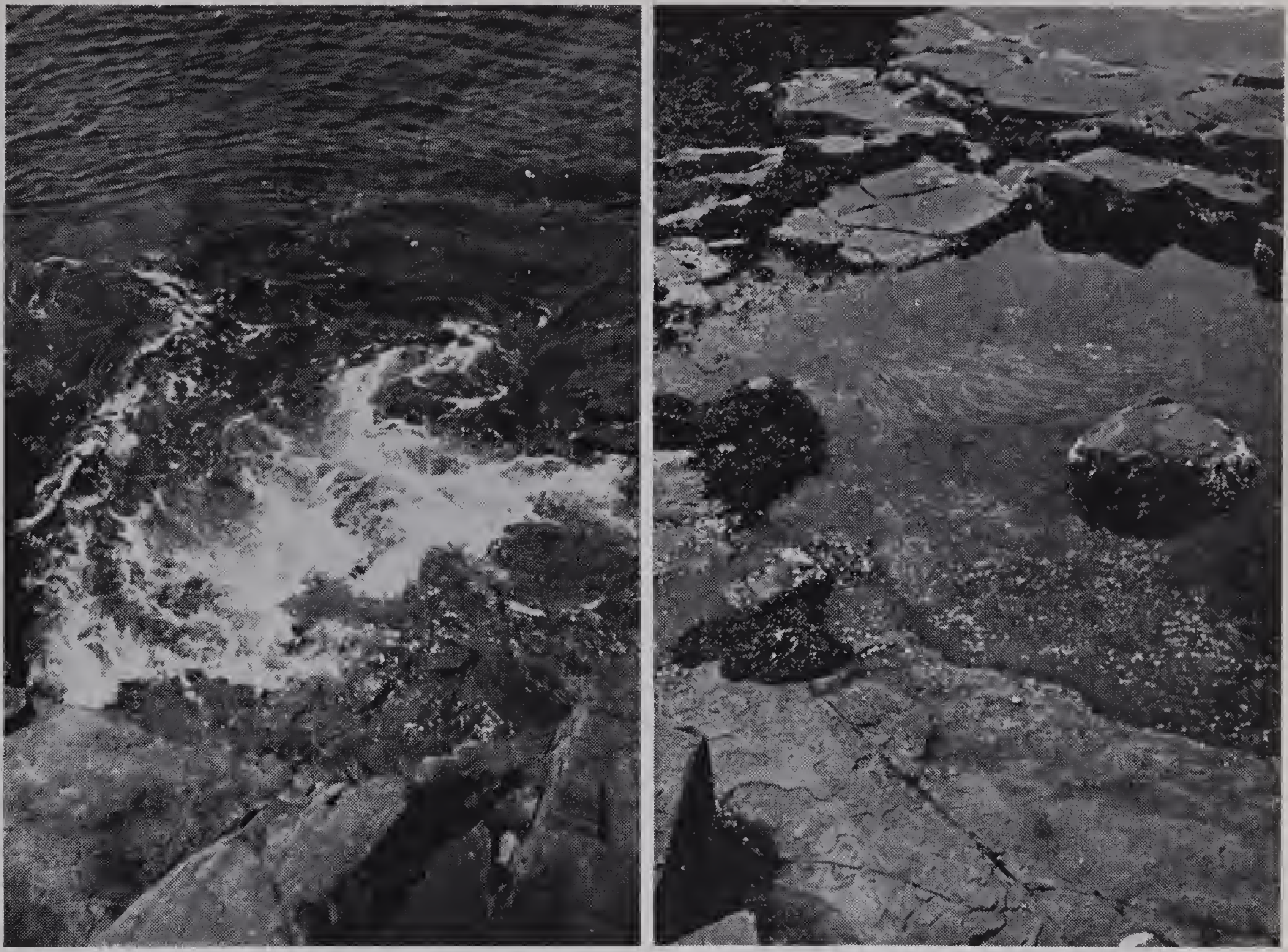
Seasonal bird study. Migration adds much to the study of birds as a hobby, for new species are arriving during the seasons of the year. Each locality has *permanent residents* which remain the year around. Certain species may be present in the winter only, moving farther north with the coming of spring. These species are called *winter residents*. The *summer residents* spend summers in a given locality and migrate southward in the fall. Many species are found only at certain times in the spring and fall. These are the *migratory birds* which are passing through a given locality on their journey between wintering areas farther south and breeding areas farther north.

Lunar rhythms. There are many folk tales about planting certain crops with various phases of the moon. Although these are interesting stories, there is no experimental data, as yet, to support them. The greatest effect of the moon is seen along the coasts, because the moon is mainly responsible for ocean tides. Tidal extremes vary in different parts of the earth, depending on the shape of the coastline. In the Bay of Fundy, located between Maine and Nova Scotia, 50-foot tides have been measured. On the coast of France, the Bay of St. Malo has tides of 39 feet. Although most regions do not have such spectacular tides, the rhythmic rise and fall of water level affects the lives of the organisms living within this zone of tidal influence.

Many marine biologists spend their time studying the ways in which plants and animals are able to adjust to the changing conditions of such an environment. The greatest problem is the danger of drying out at low tide. The small fishes and crustaceans find protection in the waters of the tidepools left as the water recedes. Many limpets and snails resist drying out by clamping down tightly on the rocks. Mussels and barnacles preserve moisture by closing their shells tightly. Some sessile sponges and tunicates live under rock ledges protected by sea weed, which covers them when the tide is out.

Drying is only one of the problems the intertidal organisms face. In both summer and winter, tides cause wide variations in temperature. Fresh water from rains alters the salt content of tidepools. Thus, the organisms inhabiting the intertidal zone must adjust to a great variety of changes.

On certain nights from March to August, cars are parked bumper to bumper on the coast highway of California. Thousands of beach fires, added to the light of the moon, create a spectacular scene. The people are waiting for the turning tide, at which time the beach will be left shimmering with thousands of fish. These fish, called *grunion*, are caught and roasted over the fires. The grunion's behavior offers a precise example of lunar periodicity. Exactly at the turning of the tide on the second, third, and fourth nights of the highest night tides, pairs of these fish swim up the beach with the breaking waves. The female digs into the sand and deposits eggs about three inches below the surface. The male fertilizes the eggs, and on the next wave, the pair slips back into the sea. The eggs remain in the sand until the next unusually high tides, about ten days later, at which time they are washed out of the sand. The eggs

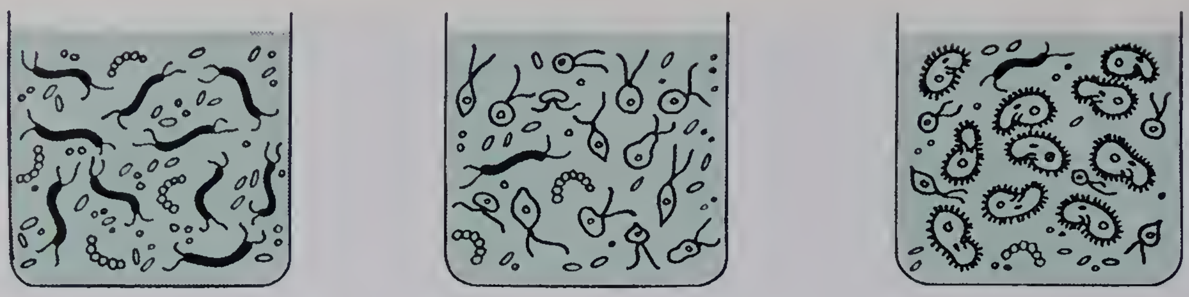


50-6 The photograph on the left shows a tidepool at high tide, and the one on the right at low tide. Note the barnacles and brown algae which are always exposed at such periods. (Kinne—Photo Researchers, Inc.)

hatch as soon as they are immersed, and the tiny fish swim away. Several marine annelid worms have also been observed to swarm and breed at definite phases of the moon.

Annual rhythms. Many of the reproductive cycles of plants and animals are associated with seasonal changes and occur in a yearly rhythm. The female bear has her young during the winter in the protection of her den. Birds nest in the spring, thereby insuring full growth of the young before winter. Wildflowers bloom in the spring and produce seeds for the development of the next generation. Deciduous trees lose their leaves in the fall. These are all familiar expressions of annual cycles. You will be able to name many more.

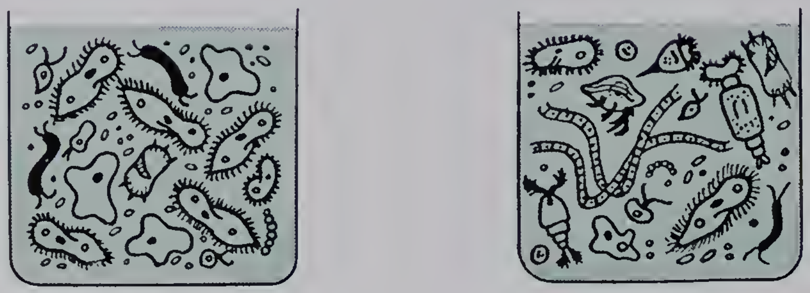
What is the value of periodicity? As you are now well aware, an organism must be able to meet environmental changes in order to survive. You have seen many ways in which various organisms adjust to changes in the environment. The establishment of a synchronized rhythm for any entire population is of value for the survival of the species. The behavior of swarming grunion insures the aggregation of males and females so the eggs can be fertilized. Male and female gametes of the oyster are shed into the surrounding water at the same time. Even though a female oyster may produce 114,000,000 eggs, her efforts would be futile if a neighboring male did not release sperm at the same time. The search for fac-



Pioneer stage—bacteria

Flagellate stage

Colpoda stage



Paramecium—ameba stage

Climax stage—balanced

50-7 Succession in a jar of water.

tors causing synchronized behavior in populations occupies the time and efforts of many biologists.

Changing biotic communities. We have seen some of the daily and seasonal changes occurring in various communities. Plants and animals are continually on the move, but since the changes in plant populations of an area usually occur slowly, they are not always easy to identify. As plants change, animals find new homes. This changing of communities is called ***succession.*** If an area within an ecosystem were completely cleared of living things, the natural changes bringing about its populations would be more apparent. The gradualness of changes results in a relatively stable community in equilibrium with the local conditions.

Winds, fires, volcanic activity, and other events in nature, as well as man's clearing, may destroy the organisms living within a natural area. Then, if the area is left alone, succession starts. Eventually a permanent community will reclaim the region. From beginning to climax may take as long as 100 years.

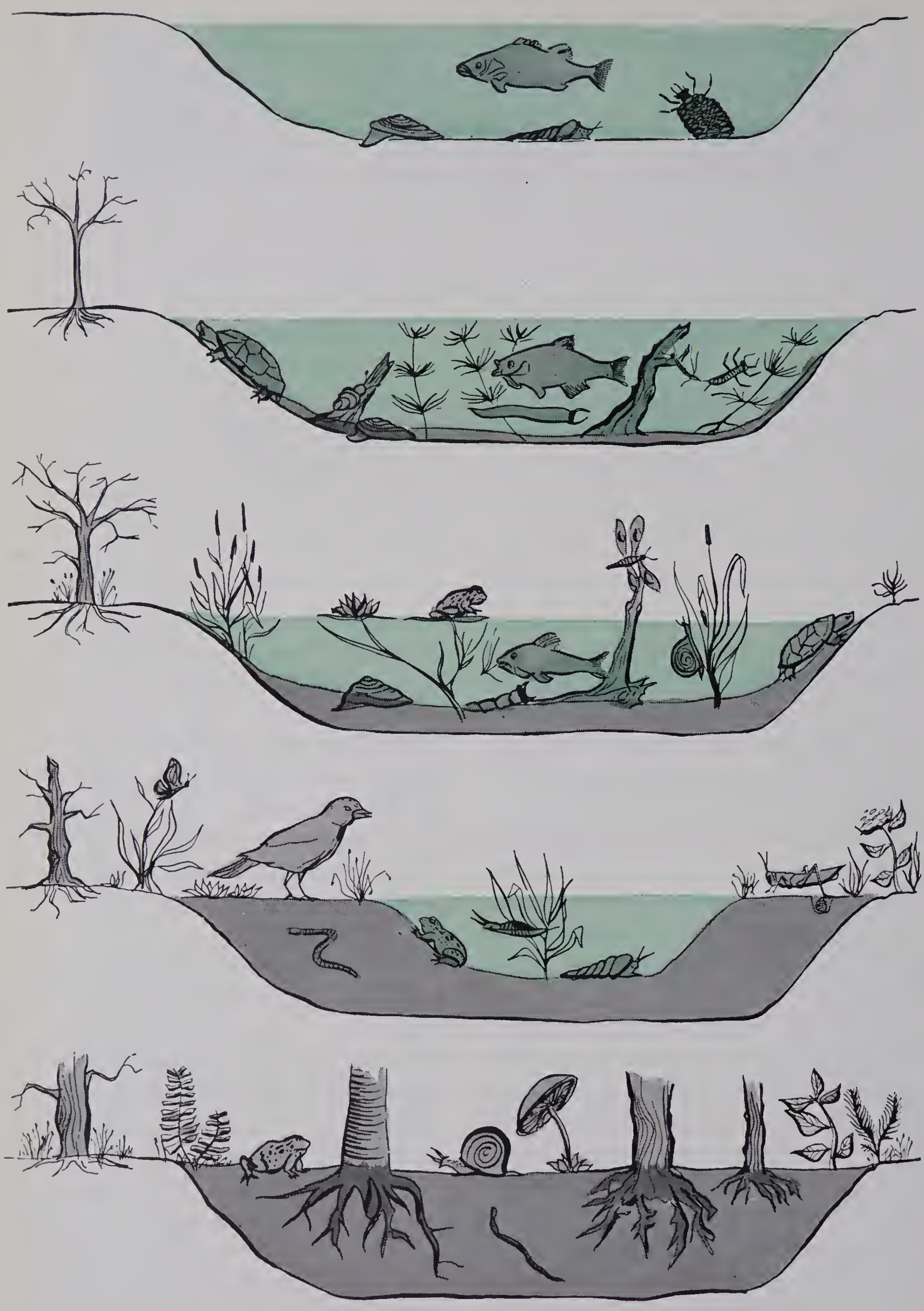
Succession can occur even in a jar of water. If the culture medium is made by boiling hay and then exposing it to the air, it will soon be teeming with bacteria. Since the bacteria are the first organisms to enter the area, they are called ***pioneers.*** If a few drops of pond water containing several kinds of protists are added to the bacterial culture, the protists will multiply at varying rates. The flagellate population thrives on the bacteria, but as their numbers increase, their food becomes scarce, and they begin to dwindle. The disappearance of the flagellates is also speeded up by an increase of *Colpoda,* a ciliate resembling the paramecium. As the *Colpoda* feed on the flagellates, the medium becomes less acid and the *Colpoda* population is replaced by the increasing numbers of paramecia and amebas, which can adjust to a more alkaline environment. As the amebas begin to increase and consume more ciliates, the ciliate population declines. This succession may take several months, and at the end of this stage, the organisms will all die unless more nutrients are added. If we were to add a few cells of green algae to the jar, they would multiply and the addition of a few drops of pond water might allow some rotifers and crustaceans to develop. At this stage, there are a few of all the organisms in the water, and as long as the plants receive enough light to manufacture food, the numbers of each kind will remain about the same. This stable, or balanced, system may remain for months or even longer. The balance would, then, be the climax condition of the ecosystem in the jar.

Natural succession in a forest. Whenever a tree falls in a forest, succession begins. This type of succession is much more complex than that occurring in a hay infusion, and lasts for a great many years. Whenever rocks are put in a bay for a breakwater, or wooden or steel piles are sunk for a pier, ecological succession occurs. Wherever succession has been studied, the sequence of organisms and their time of appearance can be predicted with surprising accuracy.

To examine a more complex series in a succession, we shall start with a section of bare soil in an open area. It might be a region devastated by fire or one cut for trees and not reseeded. We shall locate it in a broad-leaved forest in the eastern United States, where beech and sugar-maple forests once grew over much of the land. First, the seeds of grasses and other open-field plants that may have been dormant in the soil or are carried in by animal or wind find the environment satisfactory. A meadow is produced by these pioneers which may dominate and control the region for several years. Next, the seeds of elms, cottonwoods, and shrubs find their way into the meadow, marking the beginning of a forest. The larger plants shade the shorter grasses and field plants. Thus, the environment of the once open field is changed so that one might describe the area as an open, low woods. This second stage may soon become too shady even for the seedlings of the grass and shrubs, so the area will again begin to change.

The third stage may be the arrival of seeds of oaks, ashes, and other trees whose seedlings can grow well in a shady environment. These trees grow among the elms and cottonwoods and gradually assume control by becoming the dominant vegetation. Finally a dense forest begins to form. The ground becomes moist and fertile, and beech and maple seedlings outdistance all other species in the competition for a place to live in the forest. Eventually they crowd out most of the other trees. Since the beech and maple trees assume final control of the region, we refer to them as the ***climax species.*** If such a succession occurred on a ridge, the climax species might have been an oak and hickory forest. Short grasses are the climax plants in the Great Plains.

Succession in ponds and lakes. Ponds and lakes are excellent for the study of succession. As we learned earlier, the cattails and water lilies around the edges hold soil around their roots, building up the soil over a period of many years. When this occurs, the pond actually grows smaller. By closely examining the organisms from the pond's edge outward to the terrestrial climax plants of the region, we can then predict the succession of plants and animals that will gradually move inward until the pond is obliterated. The size of the pond or lake, the way in which its water is supplied, and its location also determine



50-8 Schematic diagram of succession in a pond. A: pioneer, open-pond stage; B: submerged vegetation stage; C: Cattail stage; D: sedge meadow stage; E: climax forest stage.

the extent to which succession fills it in. These conditions also determine the time for succession to occur and whether it will take a few years or hundreds of years.

On August 17, 1959 an earthquake occurred in the Madison River Canyon of Gallatin National Forest in Montana. A new lake was formed and much land on the mountainside was cleared when tons of earth, rocks, and trees fell into the canyon. Biologists are currently studying the changes occurring in the new lake and clearings. A knowledge of ecological succession enables us to predict the changes, but phenomena such as this earthquake provide us with opportunities to prove our theories. For this reason the United States Forest Service has set aside 37,800 acres of the earthquake area as a preserve for public enjoyment and scientific study.

The drama in nature goes on endlessly. Conditions in any given area are never permanent or static. Each society of plants that occupies the area alters the environment, and often makes it unsuitable for more of the same plants but favorable for other kinds that move in. Over a period of time these changes in plant population prepare the way for the climax vegetation. Since the animal population is dependent on the plant population, the kinds and numbers of animals change as plant succession occurs.

IN CONCLUSION

Periodic changes in communities are brought about by regular variations in light, temperature, and climatic conditions. These physical factors may act as stimuli or inhibitors, controlling the behavior of organisms. Rhythmic behavior sometimes continues, however, even when an animal has been placed in a laboratory under constant conditions. Therefore many biologists say that some animals have an "internal clock."

In cleared areas an orderly progression of living things occurs. The pioneers make the environment right for other organisms, which in turn create conditions allowing different plants and animals to move in. Gradually a balance is achieved and the climax vegetation dominates the flora. Ecological succession can be studied in an ecosystem as small as a jar of water or as large as a forest.

The next chapter will present some theories to explain why animals and plants may be found in certain areas of the world and not in others.

BIOLOGICALLY SPEAKING

climax species
diurnal
estivation
hibernation
migration
nocturnal
periodicity
pioneers
rhythmic
succession
winter sleep

QUESTIONS FOR REVIEW

1. The owl and the hawk are both predators. Do they compete with one another? Explain.
2. What evidence is available to indicate that daily rhythms are not merely a matter of light and dark stimuli?
3. What factors make the equatorial environment favorable for growth of many organisms?
4. In what ways do animals adjust to seasonal changes?
5. In what ways are hibernation and estivation similar? How are they different?
6. What explanation has been given to account for the migrations of the monarch butterfly?
7. What environments are directly affected by lunar rhythms?
8. How does the grunion's behavior demonstrate lunar periodicity?
9. Of what value is periodicity to survival of some species?
10. By what methods can succession be studied?

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss why man's activities are not entirely governed by external rhythms.
2. Discuss the senses that are well developed in nocturnal animals.
3. Discuss the ways in which a desert and an arctic treeless plain are similar.
4. Review and discuss possible causes for migration in birds.
5. Name and identify the permanent residents, winter residents, and summer residents of the bird population in your area.
6. What climax communities exist in the area where you live? Can you identify any stages leading toward this climax?

CHAPTER 51

BIOGEOGRAPHY

The distribution of plants and animals. Have you ever seen or felt cobwebs floating in the breezy air of a spring or fall day? The young of many spiders spin silken threads which, when caught by the air currents, are able to support the weight of the tiny creature. Why do spiders travel in this way? Where are they going?

Perhaps, while hiking, you have stopped to pick out burrs and stickers from your socks. Cats, dogs, and other animals that roam are often covered with such seeds or fruits of weeds and other plants. As you learned in a previous chapter, fruits and seeds may have very intricate devices for getting from one place to another. A milkweed seed, for example, may travel through the air for miles on its fluffy parachute. Sailors have observed tiny airborne spiders more than two hundred miles from the nearest land. Spiders have also been found in the air at 10,000 feet altitude.

Methods of dispersal are of value to a particular species because they allow new environments to be inhabited. The baby spider and the milkweed seed are likely to float to areas where there are not so many of their own kind. Of course, if a spider lands in the ocean, or if a milkweed seed lands in a lake or on a granite cliff, they will die. However, dispersal has much to do with producing the succession about which you learned in Chapter 50.

Biogeography is the study of the distribution of plants and animals throughout the various regions of the earth. Natural methods of dispersal may extend the range of a species, or human beings may deliberately or accidentally serve as dispersal agents. For example, the Scotch broom and the French broom are shrubs that have been imported because of their delicate, almost lacelike green foliage and bright yellow flowers. In the Coast Ranges and the Sierra Nevada foothills of California, the seeds produced by these garden plants found a favorable environment. The plants have become so numerous that entire hillsides may be a vivid yellow during the blooming season. The plants have "escaped" from cultivated gardens and become locally established almost as thoroughly as though they were native.

Most people associate the pineapple with Hawaii. Actually, the pineapple is native to South America but was imported to the Hawaiian Islands where its growth and production have played a large part in the economy of this state. The introduction of European starlings, English sparrows, and Japanese beetles to North America are other examples of dispersal of animals by man.

Man actively extends his living area. He fills in tidelands with rocks and then soil. Entire communities, airports, shopping centers, and industrial sites may occupy areas that were once covered with water. New designs and building materials make it possible to build houses on hillsides once considered far too steep for human habitation. By irrigation man makes human life possible in deserts. Man's experiments in space may become a method of dispersal for man. Even now missiles being sent to the moon are sterilized to prevent establishment of microorganisms on our nearest space neighbor.

Barriers to dispersal. A frog might be transported across a large fresh water lake on a log. It could jump into the water periodically to keep its skin moist. But if the log were floating in the ocean, the salt water would cause the death of the frog. Salt water, then, can act as a barrier to the dispersal of frogs. High mountains, deserts, lakes, rivers, and soil conditions are other ***geographical barriers*** across which many plants and animals cannot pass. Continents are barriers to marine organisms. For shallow-water marine forms, deep water is a barrier. Many marine organisms are limited in their dispersal by the lowering of salt concentration where rivers flow into the sea. Similarly, many brackish-water organisms are limited to estuaries, where fresh water and sea water mix.

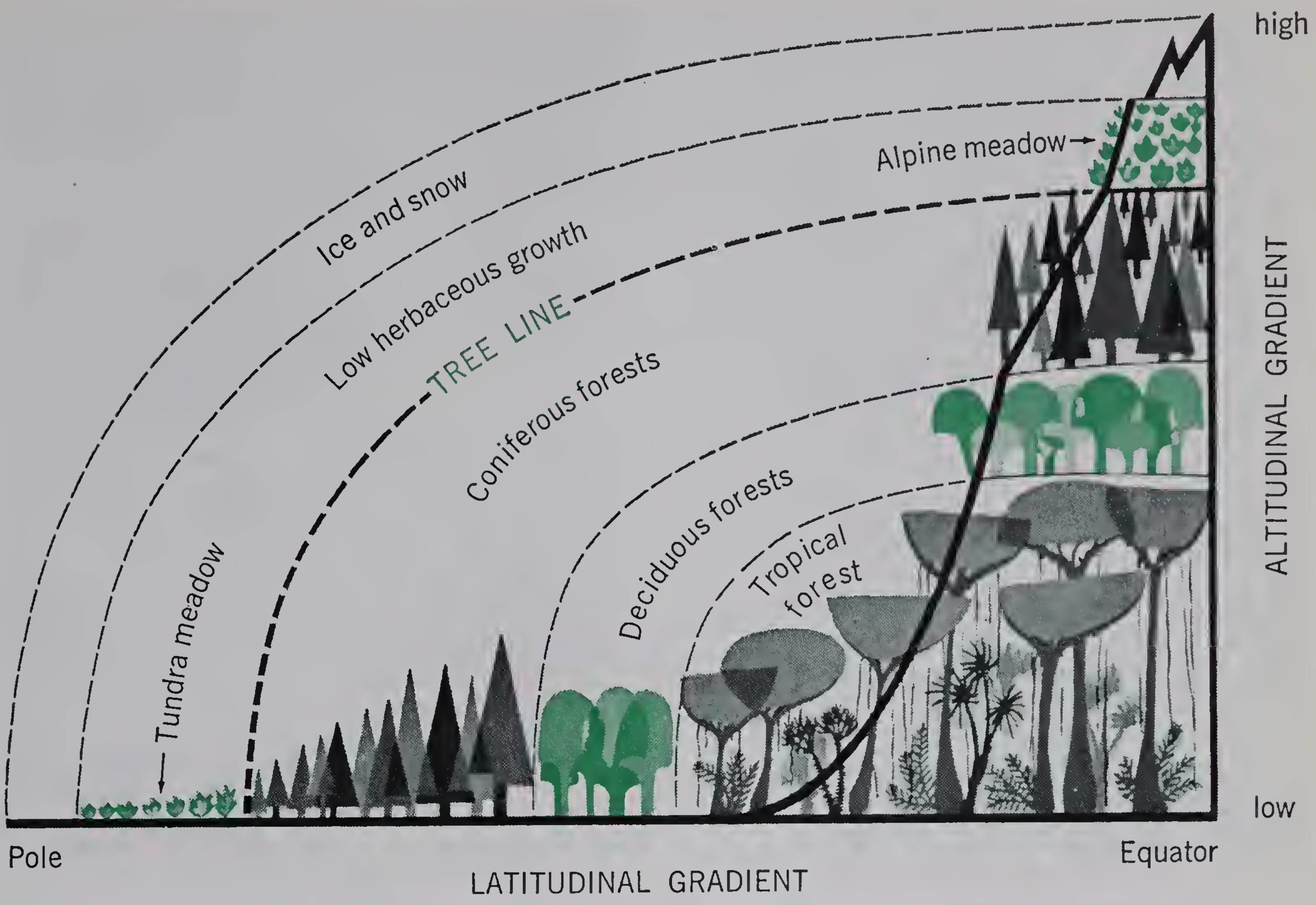
Lack of food may act as a ***biotic barrier,*** keeping animals from moving into new areas. A zebra from Africa might find a suitable habitat in Eurasia, but it would not find enough food to sustain itself while attempting to cross the Sahara desert. For deer, squirrels, and other forest animals, a desert would be a climatic as well as a biotic barrier.

Climatic barriers prevent the spread of many organisms. Although many mammals would be physically able to climb over a mountain range, the weather conditions in the mountains might keep them from doing so. A desert, with its dry, hot climate by day and near freezing temperatures at night, will stop many transients.

Major climatic zones of North America. Temperature ranges in the various regions of North America divide it into ***climatic zones.*** Northern Canada, part of Alaska, Greenland, and other land masses of the polar regions lie in the area of the polar climate. We commonly speak of these areas as the ***arctic region.*** Similar climatic conditions prevail above the timber line on high mountains. Most of Canada and most of the United States lie in the area of mid-latitude climate. This is often referred to as the ***temperate region.*** Florida is in a ***semitropical region.*** Through Mexico, the semitropics gradually become the ***tropical region.***

As the climatic regions of the earth vary from either the north or south poles to the equator, so do the principal kinds of living things. A journey from the Far North, for example, would begin with a region of ice and snow which would gradually give way to low herbaceous vegetation. Still farther south we find the large coniferous forest belts. The division between the low vegetation and the coniferous forest, called the ***tree line,*** is usually distinct. Next are the deciduous forests. Depending on the rainfall of the area in which we are traveling, the deciduous forest may give way to prairie grassland and then desert or a tropical forest.

In a few places all of the climatic zones may be found within a small area. Fig. 51–1 shows that the broad zones from polar to tropical are duplicated on a high mountain at the equator. Thus, you can see how climatic barriers can be produced by the topography of the land as well as by a change in latitude.


high
Ice and snow
Low herbaceous growth
Alpine meadow
TREE LINE
Coniferous forests
ALTITUDINAL GRADIENT
Deciduous forests
Tropical forest
Tundra meadow
low
Pole
Equator
LATITUDINAL GRADIENT

51-1 Horizontal climatic regions of the earth are similar to vertical climatic regions. Hence, life zones on a high mountain can be compared to those found while traveling from the equator to either of the poles.

Biomes — regions identified by climax vegetation. The coniferous, deciduous, and tropical forests found in various climatic zones are made up of the climax species that result as living things interact with the climate and succession occurs. A large geographical region identified mainly by its climax vegetation is called a ***biome.*** For example, a large zone encircling the Arctic Ocean of the Northern Hemisphere is a biome known as the ***tundra*** (Fig. 51–2). Since there is no large land mass at a corresponding latitude of the Southern Hemisphere, the area of southern tundra is very small when compared to that of the North. The climate of the tundra is extremely cold, and the ground is permanently frozen a few feet below the surface. During the continuous daylight of summer, the surface thaw produces saturated bogs, many streams, and ponds.

Mosses and lichens form the prominent perennial vegetation, although some dwarf birches, alders, willows, and conifers may be found. The annual plants have a rapid growing season, and many produce large, brilliant flowers even when interrupted by periods of freezing temperatures. Most of the birds are summer migrants, but the ptarmigan is a permanent resident. Many of the inhabitants of the tundra, such as the Arctic hare, lemmings, Arctic foxes, and polar bears have white coats that act as protective coloration. In the summer insects are very numerous, and the eggs they produce are resistant to freezing. Herds of caribou visit the tundra to graze on the moss and lichens.

51-2 The boulders shown in this tundra scene are covered with mosses and lichens, the prominent perennial vegetation in this biome. (Walter Dawn)

The coniferous forest. Another biome occurs in Europe, Asia, and North America just south of the tundra. As with southern tundra, there is no large corresponding zone in the Southern Hemisphere, as there are no large land masses in these latitudes. Sometimes this large coniferous forest is called the ***taiga*** (*ty*-gah). In this region the growing season may be as long as six months, although the winter temperatures may be as severe as in the tundra. The tree line marking the transition from the tundra to the taiga may be quite noticeable. At this point the most obvious tree is the spruce. In the taiga, soil is shallow because of glacial scraping years ago.

Farther south the broad coniferous belt covers much of Canada where alders, birches, and junipers may be found in groves. Here, where fire has destroyed large areas and where succession has occurred, the pioneer grasses are followed by aspens and birches. These are eventually replaced by the spruces and pines and firs that form the climax community. Along the coastal ranges of Washington, Oregon, and California are magnificent stands of pine, spruce, and redwoods. Here giants reach a height of 200 feet or more. Rainfall may be as heavy as 80 inches per year, and fogs blanket much of the area.

The prominent permanent residents of the coniferous forests are many. Moose are plentiful in areas that have not been excessively hunted or where they are protected. Black bears roam these forests. Martins, wolverines, and lynxes may be found. Squirrels, voles, chipmunks, rabbits, and mice may be preyed upon by the bobcat, fox, and wolf. Beavers and porcupines are found in many of the coniferous forests. During the summer months many birds breed in these forests, but in the fall they migrate south. The numerous insects and other invertebrates found in the coniferous biome during the summer lie dormant during the cold winter months.

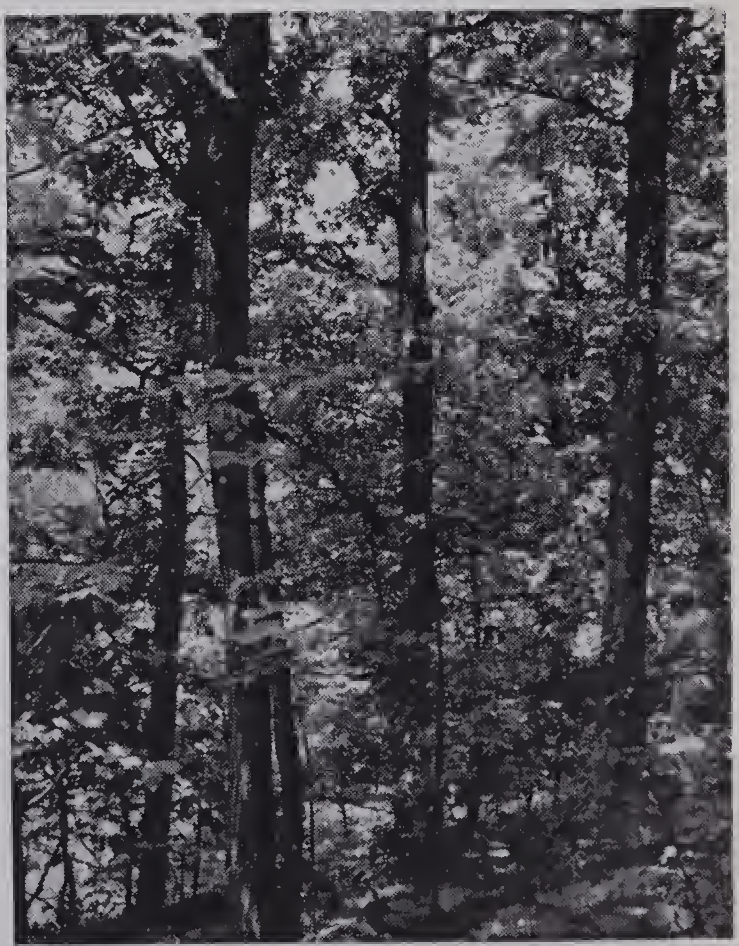
The deciduous forest. In areas of the temperate zone the growing season may be six months or more. Rainfall averages around 40 inches per year and, where the soil is suitable, large ***deciduous forests*** occur. The eastern United States, England, central Europe, and parts of China and Siberia are or once were covered with large stands of deciduous trees. Although a similar zone occurs in South America, it is limited in size by inadequate rainfall.

Local conditions of soil, drainage, and variations in climate throughout the temperate zone provide conditions necessary for different climax communities. In the United States the beech-maple forests are found in the north central regions while the oak-hickory forests are common in the western and southern regions. Although most of the native chestnut trees were destroyed by blight, oak-chestnut forests formerly covered much of the Appalachian Mountain chain. Other common deciduous trees found in the temperate zone are sycamore, elm, poplar, willow, and cottonwood. Although each of these specific forests has its typical animal species, many animals are characteristic of deciduous forests. Deer are the common herbivores. Foxes, martins, raccoons, and squirrels inhabit the area. Wolves may wander between the taiga and the deciduous forests. Woodpeckers and other tree-nesting birds are plentiful.

The deciduous forest undergoes great seasonal change. In late spring and summer the trees are green, and shrubs growing in their shelter produce beautiful blooms. During the fall many areas are turned into artistic splendor by the multicolored leaves of trees preparing for winter. In the winter the bare branches contrast with a white blanket of snow.

The deciduous forest biome is one of the most important regions of the world, as it is here that man has achieved his greatest cultural and technological development. Cultivated plants have replaced many of the naturally occurring trees. Large forests have been replaced by cities.

The grasslands. In vast areas where rainfall is between 10 and 30 inches per year, ***grasslands*** occur. The variable rainfall is not enough to support large trees, but is sufficient for many species of grass. These natural pastures have always been used by huge herds of grazing animals. However, improper use of the land by man has turned thousands of acres of grassland into bare wasteland



51-3 The oak-hickory woodland is a good example of a deciduous forest. (U. S. Forest Service)

51-4 When scattered trees are present, grassland areas are called savannahs. Here, a Southern savannah has Spanish moss hanging from the live oak trees. (Brunswick-Glynn County Chamber of Commerce)

by erosion of the topsoil. When the grasses are destroyed, essential topsoil is worn away by water and wind, with tragic results.

In North America the grasslands occur in the Great Plains east of the Rocky Mountains. The tropical grasslands of Africa, with their giraffe, zebra, antelope, ostrich, and lion populations, are a familiar picture to most of us. A *savannah* is a grassland with scattered trees. In the West the oak-grass savannah is familiar. South America also has large areas of savannah. In Australia the grasslands and savannahs support cattle and sheep for food, grazing kangaroos, and burrowing animals. Wild dogs are found very often and are prominent predators.

In America great herds of bison and antelope once grazed on the grasses of the plains. Burrowing mammals such as hares, prairie dogs, ground squirrels, and pocket gophers are still abundant and form an important link in the food chain, for they are eaten by weasels, snakes, and hawks. Locusts and grasshoppers are important members of the insect population.

The desert biome. It may surprise you to learn that there are hot and cold ***deserts.*** Death Valley, where the creosote bush is the climax vegetation, is a representative hot desert. In the typical cold desert, occurring in the temperate zone, the sagebrush is the dominant shrub (Fig. 51–5). Cold deserts are found in several of our northwestern states. In both hot and cold deserts, the plants are xerophytic; that is, they are adapted for living in areas where the rainfall may be only 10 inches per year. The leaves are small, with thick, leathery outer layers that help conserve the plant's water. Other desert plants, like the cacti, have no typical leaves at all. Spines are nonfunctioning leaf vestiges.

Desert animals also have special adaptations. The reptiles, some insects, and birds excrete nitrogenous wastes in the form of uric acid. Uric acid can be excreted in an almost dry form, thus conserving valuable water. Mammals, however, cannot do this. They excrete nitrogenous waste in the form of urea dissolved in water. This involves the loss of water from the mammal's body. Most desert mammals burrow during the day to conserve moisture. Some rodents are able to live on the small amount of water in the seeds and fruits they eat. Others get water from the tissues of cacti or other water-storing plants.

Desert herbs, grasses, and flowering plants burst forth in growth and color in a surprisingly short time after a rain. Many of these plants are able to complete their cycle of growth, flowering, and seed production within a few weeks. Some of the larger perennial plants have very long tap roots. Most desert plants can hold water in the angles between the leaves or in spongy tissue.

The rain forest. Although each *rain forest* may have its particular flora and fauna, the conditions and ecological niches are similar. In areas of abundant water supply and a long growing season, life flourishes. There is a *temperate rain forest* on the northwest Pacific Coast in the Olympic Peninsula of Washington. The *tropical rain forests* are found on and near the equator, including most of Central America, northern South America, central Africa, southern Asia, the East Indies, the South Pacific Islands, and northeastern Australia. The seasonal variation in temperature is usually less than that of the day and night.

The numbers of plants in a rain forest produce a dense growth. Tall trees have shorter trees growing beneath them. The canopy produced may be so dense that few plants can grow on

51-5 The cold desert occurs in northern latitudes. Note the sagebrush, which is common in these areas. (Bureau of Land Management)

51-6 A temperate rain forest is shown on the left while a tropical rain forest appears on the right. (Left: U. S. Forest Service; right: Walter Dawn)

the ground. Even so, many smaller plants have become adapted to life in the tropical rain forest. Some have evolved long vines that make it possible to have roots in the moist ground and leaves high up toward the daylight. Other small plants grow high among the trees so they can receive sufficient light for photosynthesis. Most tropical rain forest plants have very large leaves, as the conservation of water is not a problem for them. The critical factors are finding a place to grow and obtaining sufficient light for photosynthesis.

Epiphytes (*ep*-i-fyts) are plants that attach themselves to trees, sometimes 100 feet or more above the ground. They have thick, porous roots adapted to catching and holding rainfall. Many epiphytes also have leaves arranged so that they catch water, insects, falling leaves, and other debris. As the insects decompose, essential minerals are released for the epiphyte's use. Many species of orchids, mosses, ferns, lichens, and members of the pineapple family are epiphytes. Even though epiphytes do not take nourishment from the plants upon which they grow, they may cause minor injury by shading the leaves of the supporting plant or causing limbs to break from the weight. Spanish moss is an epiphyte (Fig. 51–4).

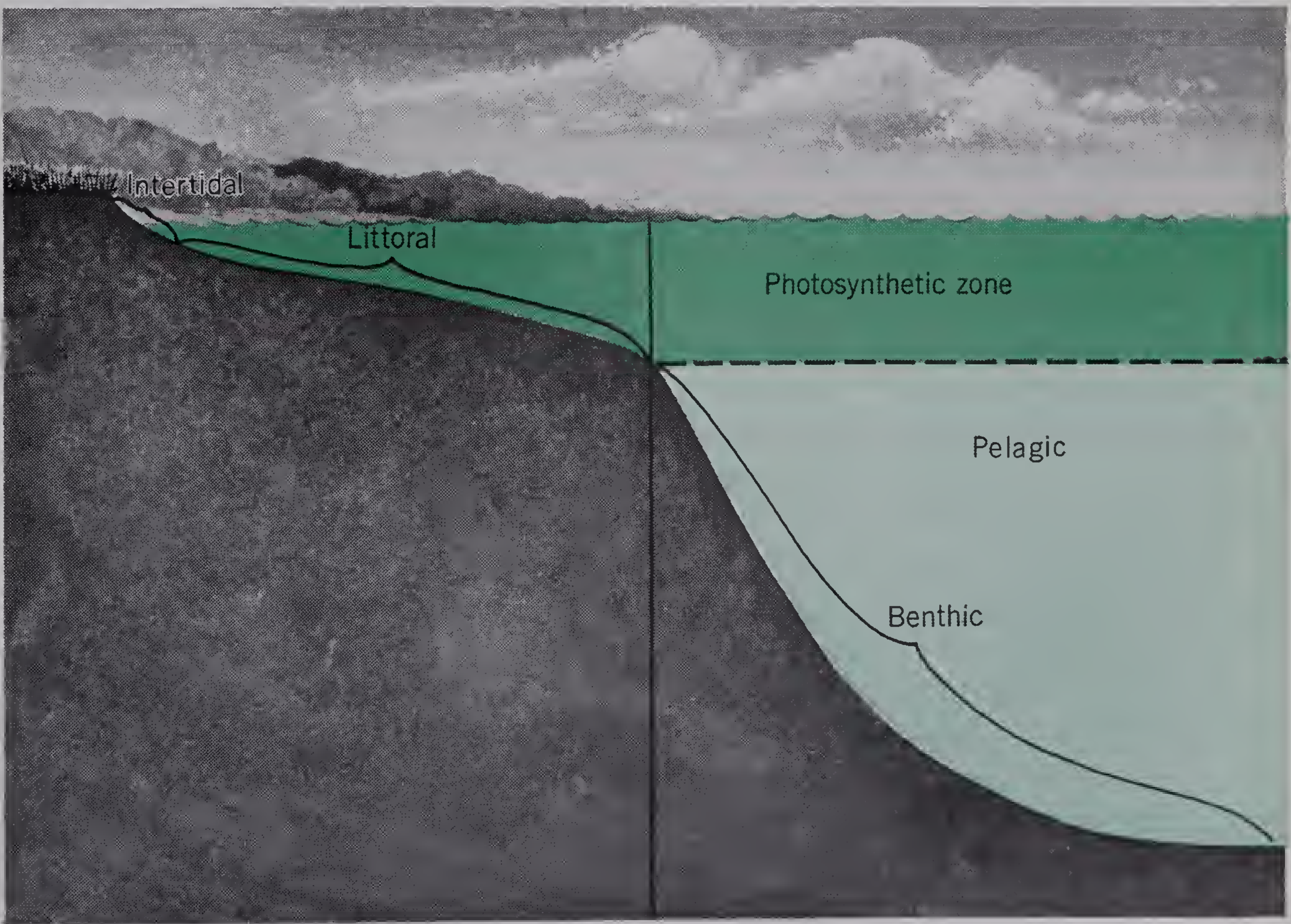
Although animal life in the rain forest is plentiful, it may not be obvious to the casual observer in the daytime because so much of it exists high in the trees. Except for an occasional bird call or chatter from monkeys, the day in a rain forest is relatively quiet. But toward evening everything seems to come alive. The crickets and tree frogs begin singing, and the birds make more noise as they search for food. The tree-dwelling monkeys chatter excitedly and howl for the last time before settling down for the night. Ants, beetles, termites, and other insects are numerous, supplying many animals with food. The nocturnal carnivorous cats, such as the jaguar in South America, the leopard in Africa, and the tiger in Asia, hunt for monkeys, deer, and other animals.

Many people confuse jungle growth with a rain forest. A typical rain forest is climax vegetation. Jungle is extremely dense ground growth that occurs along the edges of rivers or on land that was once cleared by man or by some natural means like fire. If left alone, most jungle eventually becomes rain forest. Jungle is therefore a kind of immature rain forest.

The marine biome. The oceans cover more than two thirds of the earth's surface and support a surprising quantity and variety of living material. The ***marine biome*** may be divided into the bottom, or *benthic* zone, and the ocean, or *pelagic* zone (Fig. 51–7). The shoreline comprising the continental self is the *littoral* zone. This is the most productive area of the marine biome. The pelagic zone, including waters to a depth of about 600 feet, allows the penetration of some light. It is in this zone, then, that photosynthesis occurs in microscopic suspended algae as well as in the large drifting algae. Near the shore the area periodically covered and uncovered by water is called the *intertidal* zone. This is exposed at low tide but covered at high tide.

Although plants in the ocean play an important role in energy production, they do not have as great a controlling influence on the environment as do the plants on land. Compared to the terrestrial environment, the ocean provides a stable condition for life. With the exception of the intertidal zones, estuaries, and changing currents, the temperature and salinity remain fairly constant.

The basic food of the pelagic zone is the plankton. This is composed of diatoms, dinoflagellates, unicellular algae, protozoans, and the larval forms



51-7 The ocean may be divided into several zones, each having characteristics which determine the kinds of organisms able to live there.

of many animals. Many copepods, small shrimp, small jellyfish, and worms are considered to be part of the plankton, even though they can swim poorly. The copepods feed on the microscopic diatoms and algae and in turn provide the major food for the largest animal of all — the whale. The food chains of the ocean involve many carnivorous fishes, squids, and sharks.

Animals that live beneath the photosynthetic zone depend on sinking plankton, dead animals, and the swimming organisms that pass between the levels. Many of the forms that constantly inhabit the deeper dark regions of the ocean are very unusual in appearance, often having luminescent organs.

Recent studies have revealed many animals living on the deep-sea bottom. For their nutrition, deep-sea scavengers depend on the descent of dead animals from above. Bacteria living in the soft ooze on the bottom break up complex organic molecules of dead organisms that have settled there. However, mineral exchange occurs in the ocean as on the land. Currents cause upwellings of the deeper waters and the minerals and compounds essential to life are again brought to the surface, where they can be synthesized into organic compounds by the phytoplankton and larger algae. The process of upwelling brings colder waters, rich in sedimentary materials, to the surface. Upwelling is a very conspicuous phenomenon near the coasts of Morocco, southwest Africa, California, and Peru. Since the rising waters bring nutrients to the photosynthetic zone, you can see why these areas are very rich in phytoplankton. Associated with the abundance of food producers are the many consumers. These are very popular fishing areas.

The intertidal area of the littoral zone corresponds to the tropical rain forest on land. Here, in spite of greater variations in temperature, salinity, and exposure to drying conditions, life is abundant. Space for growing is at a premium. Algae and many tiny colonial animals attach to the shells of snails, limpets, and kelp, as well as to rocks. Epiphytic algae are found on most kelps. Snails, periwinkles, and barnacles can be found high on rocks where they are exposed to the air for long periods of time. They conserve water by clamping down tightly when the tide is out. Then, when covered by the tide, they browse on the algae. Other herbivores present in the intertidal zone are shrimp, small fishes, and copepods. Clams, mussels, oysters, and sponges filter many forms of microscopic life from the water. The starfish, sea anemone, larger fishes, octopus, and squid are carnivores. Sea urchins "graze" on algae. Various worms, crabs, and hermit crabs are familiar scavengers of the intertidal zone. Other worms and bacteria play an important role in breaking down waste materials and dead organisms for the recycling of essential elements.

The fresh-water biome. The ***fresh-water biome*** includes bodies of standing water such as lakes, ponds, and swamps, as well as bodies of moving water such as springs, streams, and rivers. Many of the plankton organisms of the ponds and lakes do not survive under conditions of running water. The strength of the current and the type of bottom are factors that determine the kinds of life able to inhabit a stream. A bottom of shifting sandy soil greatly limits the life in a stream, but in streams with a sluggish current and a sandy bottom, many burrowing forms are found among rooted vegetation. Stony streams provide a habitat for actively swimming or

51-8 The fresh-water biome has its peculiar plants and animals, each suited to the environment found there. (American Forest Products Industries, Inc.)

clinging animals. The larvae of caddis flies, mayflies, dragonflies, and dobsonflies are common inhabitants of stony brooks and streams, where they provide part of the trout's diet. Algae grow attached to the rocks, stumps, or stones. The plankton organisms of lakes have already been discussed. These floating organisms are found in streams only as occasional transients.

Water temperature is important to the organisms living in an aquatic environment. To raise the temperature of water requires a large amount of heat. Also, when water evaporates, much heat is absorbed from both the water and the atmosphere. These properties of water are well known to all who enjoy diving into a pool on a hot summer day. Upon coming out of the pool, even a warm breeze may seem chilling as the water evaporates.

Another property of water that is very important to the inhabitants of a lake is that it becomes less dense, or lighter, as it freezes. Therefore, when water freezes, it floats on the surface. This prevents lakes from freezing solid, but it interferes with light penetration and oxygen exchange at the surface. In many lakes living things can, and often do, suffocate during the cold months of the winter season.

Water is continually passing into fresh-water organisms by osmosis. Thus, as you have learned in earlier chapters, fresh-water organisms must be able to excrete large quantities of water in order to survive. This problem is solved in protozoans by their contractile vacuoles. The efficient kidneys of the fresh-water fishes excrete the excess water that enters through the gill membranes. The problem in salt-water fishes is just the reverse. They live in water of a higher salt concentration than that in their own body fluids and are in danger of dehydration. This problem is solved in marine fishes with the excretion of salts by the gill membranes.

IN CONCLUSION

The distribution of plants and animals depends on organic, climatic, and geographical factors. Dispersal involves both a method of travel and favorable environment once a new location is reached. You know some of the special adaptations that allow organisms to live under various conditions.

The diverse forms of life have found niches in the different terrestrial, marine, and fresh-water environments. The adaptations of many plants and animals to their environments have been discussed.

The preservation of the great variety of living things for man's future use and enjoyment will be determined by his interest in and knowledge of ecology. Wherever man alters his environment, other living things are affected. Soil and water are of prime importance to the producers in man's food chain. In the next chapter we shall study the various methods of soil and water conservation.

BIOLOGICALLY SPEAKING

arctic region
biogeography
biome
biotic barrier
climatic barrier
climatic zone
deciduous forest
desert
epiphyte
fresh-water biome
geographical barrier
grasslands
marine biome
pelagic zone
rain forest
savannah
semitropical region
taiga
temperate region
tree line
tropical region
tundra

QUESTIONS FOR REVIEW

1. How do methods of dispersal limit the distribution of plants and animals?
2. Name the major barriers to dispersal and give an example of each.
3. Name and define the major climatic zones of North America.
4. What two factors are important in determining the flora and fauna within a climatic zone?
5. What flora and fauna are found in the taiga?
6. Where are the coniferous forests in the United States?
7. Where are the deciduous forests in the United States?
8. Where are the grasslands in the United States?
9. What are the differences between the hot and cold deserts?
10. What adaptations to desert climate are found in the mammals? in the birds? in the reptiles?
11. What environmental factors are found in a rain forest?
12. In the rain forests the plants are competing with one another for space in which to grow. How are the epiphytes adapted for living in such forests?
13. What extremes of environmental conditions occur in the intertidal zone?

14. What furnishes the food for organisms living in total darkness in the depths of the ocean?
15. What prevents the organisms in a lake from being frozen solid in the winter?

APPLYING PRINCIPLES AND CONCEPTS

1. What are some food chains found in coniferous forests?
2. Give some examples of organisms finding their way to a favorable new environment in spite of barriers.
3. Give reasons to support the following statement: A high mountain on the equator shows the same climatic regions as are observed from the equator to either of the poles.
4. If you were an entomologist and discovered an unusual insect destroying the pineapple plants in Hawaii, what might be a good plan to follow in searching for a biotic method of control?
5. What environmental factors differ in a coniferous and a deciduous forest?
6. Discuss the adaptations of organisms in the intertidal zone.
7. How does excretion differ in salt-water and fresh-water organisms?

CHAPTER 52

SOIL AND WATER CONSERVATION

The vital need for conservation. The human population of the world is expected to double by the end of this century or sooner. Supplying food for these vastly increasing numbers is becoming an urgent problem. Food production is dependent on the soil and its water supply. Any misuse of soil and water resources, such as we have had continually in the past, eventually cuts down on the food supply.

We must realize how short-sighted and selfish it is to continue to squander our natural resources. Perhaps people before us could plead ignorance when they turned forests and grasslands into useless dust bowls. But today we have a much better understanding of cause and effect in ecology. When we do not know the answers we should proceed with caution, carefully observing the results of the many changes we may make. Unfortunately it often takes many years to observe the results of changing an environment. You are now well aware of the importance of plants in determining the ecological setting for the animals in an area. In this chapter we shall discuss the importance of conserving soil and water in order to preserve the plant and animal populations.

Soil and its origin. Think of the earth as a gigantic ball of rock. Soil lies in a thin film on the surface of this great ball. Season after season, running water, freezing and thawing, wind, and other forces of nature crumble the rocks and form gravel, sand, or clay. These materials become mineral soil, or ***subsoil.*** In most regions the subsoil forms a layer several feet thick, representing thousands of years of the slow disintegration of rock.

The organic part of the soil comes from the slow decay of roots, stems, leaves, and other vegetable materials, and the remains of animals. We refer to the organic remains of land plants as ***humus,*** while sphagnum moss and other aquatic plants form ***peat*** in lakes and bogs.

A mixing of mineral matter from the subsoil and organic matter combine to form ***topsoil,*** or *loam.* Topsoil is the most vital part of soil, the nutritional zone of plants both large and small. It forms very slowly, at a rate of about one inch in 500 years.

Topsoil supports great numbers of bacteria, molds, and other fungi, which we refer to as the ***soil flora.*** Activities of the many soil organisms are essential to fertility of the soil. Decay, ammonia production, nitrate formation, and many other chemical processes condition topsoil for the growth of higher plants.

If you examine a soil profile along a bank or the side of a ditch, you can

52-1 Note the difference that soil can make to a crop. The corn on the left was grown in soil containing plenty of humus. That on the right is low in humus. (USDA)

see the dark topsoil and the lighter subsoil below. Under natural conditions a small quantity of topsoil washes away or is blown away each season. This is replaced by additional topsoil formed by decaying vegetation added to the upper surface. Thus, topsoil formation is a continuous process. Remember, however, that it is an extremely slow one.

The original topsoil in America averaged nine to ten inches in depth. Today it averages about five inches. When topsoil is gone, land becomes barren. In other words we are now within five inches of barrenness. The conservationist refers to this situation when he says we have lost half the battle to save our soil. Conservation of topsoil is an extremely serious problem, but it can be solved.

Cover crops and row crops. In discussing the various kinds of soil loss, we shall refer to row crops and cover crops. As the name indicates, ***row crops*** are planted in rows in cultivated fields. The soil lies exposed between the rows. Corn, beans, tobacco, and tomatoes are examples of row crops. Wheat, oats, rye, clover, alfalfa, and various grasses are grown as ***cover crops.*** These close-growing plants form a dense mat of roots which bind the soil and an aerial cover which protects the soil surface from wind and water. The relation of row crops and cover crops to the soil is very important in soil conservation.

Depletion of soil minerals. A century ago, abundant fertile land was still available to anyone who would go West to claim it. The soil contained a rich store of minerals, accumulated through centuries of the growth and decay of native vegetation. Year after year corn, cotton, and other field crops were grown in the same fields with little thought about the condition of the soil. Overproduction was the order of the day. The object seemed to be to produce as much as possible in as short a time as possible. After a few seasons the loss of fertility began to show in the form of reduced crop yield. We refer to such mineral exhaustion as ***depletion.*** Rather than heeding the danger signal, many farmers pushed the land even harder. When the soil finally became exhausted, the field was abandoned for a new and more profitable area.

A scientific view of the mineral depletion problem. It stands to reason that agricultural crops with a high food value draw heavily on soil minerals. The most critical of these minerals are nitrates, phosphates, and potash (potassium compounds). In a natural cycle plants draw minerals from the soil and organize them into the various parts of the plant body. When the plant dies, these are returned to the soil through the process of decay. But a crop plant is harvested for its food value. The minerals contained in the crop are removed from the soil permanently. This removal can continue only a few seasons before the soil shows evidence of depletion of the most heavily used minerals.

Soil that is badly depleted of minerals usually becomes acid, or sour. To correct this condition the farmer uses lime. Other minerals are restored by heavy applications of commercial fertilizer, especially superphosphate and bone meal.

Principles of crop rotation. In addition to fertilizing, which is a rapid method of restoring minerals, the scientific farmer avoids depletion by practicing ***crop rotation.*** Various crops differ in the minerals they take from the soil. Many farmers prevent mineral depletion as well as serious erosion by rotating crops in each growing area. Many rotation plans follow a three-year cycle. The first crop might be corn, followed by wheat or oats, then by grass or clover. Clover, alfalfa, cowpeas, lespedeza, and other legumes are important in a rotation cycle because they support nitrogen-fixing bacteria on their roots. As we mentioned in the discussion of the nitrogen cycle, these bacteria produce nitrates from atmospheric nitrogen.

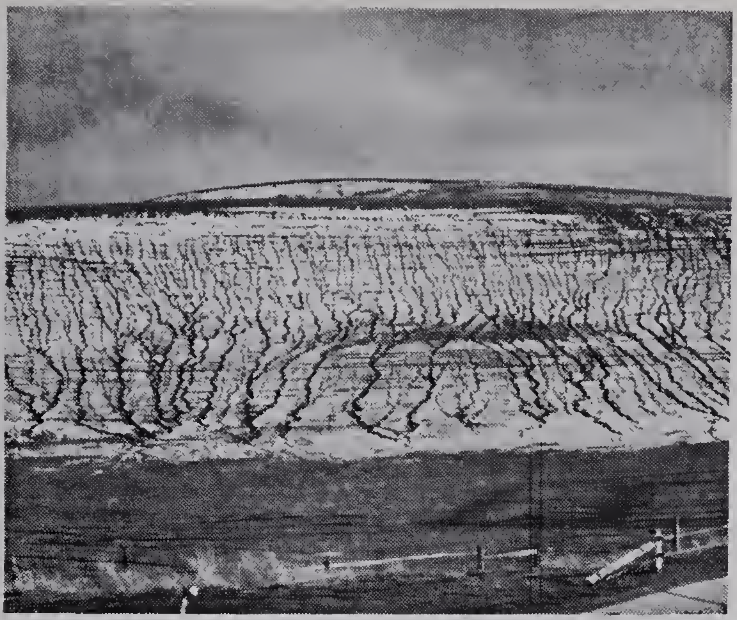
The problem of leaching. Before a field is planted, it is plowed and disked, which turns the weeds under the soil and conditions it for planting. Rains soak into the pulverized soil easily. This process is ideal for young plants, but it may cause a serious problem, especially in loose sandy loam. If the soil is properly cared for, the topsoil should be rich in minerals. These minerals must be dissolved in water, or plants cannot absorb them. As water runs through the topsoil, it dissolves minerals and carries them down below the reach of the roots of many crop plants. By such ***leaching*** action, valuable fertility is lost.

We have always assumed that frequent cultivation is good for crops. But this may not be true. Row crops especially leave much of the soil exposed to soaking rains. One method of reducing leaching is minimum cultivation. Another is the planting of cover crops between row crops. Deep-rooted crops, like alfalfa, absorb minerals from the subsoil and bring them into the plant body. If such a crop is plowed under without harvesting it, the minerals are thus returned to the topsoil.

Loss of organic matter. In a natural environment, the organic matter present in topsoil decays slowly as it is acted on by bacteria and other soil organisms. In time it would disappear entirely were it not for the leaves, roots, and other plant parts that are added to the soil each season. However, in an agricultural situation, when hay crops are harvested or when stalks of wheat or oats are used for straw, little organic matter is left to return to the soil. Sometimes weeds and native grasses are even burned off fields before plowing. This procedure is a waste of valuable organic matter which should be plowed into the soil.

If fields are cleared season after season, the organic part of the topsoil may disappear to the extent that much of the soil flora dies out. When these organisms are gone, many of the processes necessary for maintaining soil fertility cease. There are several ways in which organic matter can be added to soil. One is the addition of manure and decayed straw. An even better method is sowing grass or clover in a field, then plowing it under.

The suburban dweller may like the smell of burning leaves, but he does not recognize the value of the organic materials he is destroying. It is much more



52-2 Severe rill erosion may continue to such an extent that the rills become gullies. (USDA)

costly to buy minerals and peat moss for soil replenishment than it is to spade the fallen leaves into the soil. Many people save the leaves in a pile or heap, alternating a layer of leaves with a layer of soil. This *compost* is used to add humus to the garden the following year. Good conservation procedures are as valuable to the homeowner as they are to the nation's farmers.

Erosion, the loss of topsoil. Of all forms of soil loss, erosion is the most advanced and the most destructive. Precious topsoil from millions of acres of our most productive land now lies in riverbeds and ocean bottoms. Some has been blown thousands of miles by the wind in violent dust storms. This destruction is the tragic result of man's carelessness and shortsightedness.

Some erosion has always occurred. Before any land was cultivated, soil formation generally kept pace with this slow blowing away or washing out of the soil. But when land was stripped of its natural vegetation and poor farming methods exposed it to forces of water and wind, a far more dangerous, accelerated erosion began.

Much of the land that is badly eroded today was abandoned for agriculture when the minerals became depleted — a result of overcultivation. With the rapid expansion of agricultural industry, more and more areas were cultivated for crops. In eagerness to make every inch of land pay, many farmers began cultivating hillsides, river bottoms, and all other available locations rather than increasing yields from land already cultivated.

In hilly forest lands, where oak and hickory trees were thriving in shallow topsoil, native vegetation was cleared to make more tillable ground available. Such lands were excellent for forests but were unsuitable for crops. Soon they were abandoned to the ravages of erosion or were left for families to eke out an existence from a few patches of dwarfed corn and vegetables.

Water erosion. One form of water erosion, known as ***sheet erosion***, occurs when water stands in a field during a flood, then flows away gradually. The water carries a thin layer of soil with it as it flows away. When the water is gone, the land is left at a level much nearer the sterile subsoil. A few such floods may leave the land worthless.

In rolling and hilly sections where the rain falls on exposed soil, raindrops carry with them particles of soil, forming tiny channels, or rills, as they trickle down the slope. This process is the beginning of ***rill erosion.*** Each time water flows down the slope, it follows the same rills. These deepen and widen much as a stream increases the size of its bed. A more advanced stage known as ***gully erosion*** may follow. If the gully is not checked, it may in time become a canyon (Fig. 52–3) This can be avoided even on cultivated hillsides when proper conservation methods are used.

52-3 This gully is about 150 feet deep and the land it was formed from was once a productive crop area. (Soil Conservation Service)

Contour farming. When land is cultivated up and down a slope, the furrows act as man-made rills. Each time it rains, water pours down the furrows and enlarges them. They can become gullies in a short time.

The solution to this problem is logical. Plow around the hill rather than up and down, a method called *contour farming.* When furrows are plowed around the slope, each one serves as a small dam to check the flow of water. Water stands in each furrow and then soaks into the ground. If this simple practice had been followed long ago, our lands today would be richer and our rivers deeper and clearer.

Strip cropping. The extremely valuable soil conservation practice of ***strip cropping*** frequently combines two important measures. Broad strips are cultivated on the contour of a slope for growing row crops such as corn, cotton, potatoes, or beans. These strips alternate with strips in which cover crops such as wheat, oats, clover, alfalfa, or grass, are grown. These cover crops completely cover the surface of the soil and hold it securely. As water runs from the strip of row crop, it is checked upon entering the strip of cover crop.

Frequently clover is used as a cover crop. Nitrogen-fixing bacteria, associated with roots of clover, alfalfa, and other legumes, return the various nitrogen compounds to the soil. Strips may be alternated every few years with the result that water erosion is checked continually and fertility of the soil is maintained.

Terracing. The practice of ***terracing*** is used extensively to check the flow of water on steeply sloping land. A long slope is broken into numerous short ones by forming a series of banks. A type of machine, the terracing grader, is used to form flat strips on the contour of the

52-4 Terraced hillsides such as these in Idaho prevent runoff and the resulting erosion. (Bureau of Land Management) slope. Each strip is divided from another by a bank. Drainage ditches at the base of each bank conduct the water around the slope.

Gully control. When large gullies have already formed, measures other than those discussed previously must be used. One of these is planting the slopes of the gully with trees, grasses, or other plants to act as soil binders and prevent further widening. Deepening may be prevented by building a series of small dams. The dams slow the flow of water and soil gradually fills the gully.

The problem of wind erosion. Wind erosion is a critical factor in western Texas, Kansas, and Oklahoma. The prevailing strong winds blow from the south, especially during the spring and summer months. Originally, native grasses and other plants bound the soil firmly in place with their extensive, shallow root systems. Much of this land was extremely fertile and suitable for growing cereal crops and, as a result, extensive areas were plowed for agriculture. This practice began to take its toll in the 1930's.

During the spring and early summer months, the soil was moist enough to hold its place, but with the late summer drought the strong hot winds blew the dry topsoil away. Entire fields were covered with fine particles of topsoil carried in dense clouds during a dust storm. Abandoned fields added to the growing wasteland. The farmer who was fortunate enough to hold his soil in check was powerless to stop the tons of soil that blew onto his land from other areas. There was nothing left but to abandon the homestead with its half-buried houses and barns and join the procession of landowners out of the growing "dust bowl," as the area came to be called.

52-5 Planting rows of trees as windbreaks helps prevent serious erosion of the soil due to wind. (USDA)

Control of wind erosion. Wind erosion is an especially difficult problem because it involves such large areas. Any local wind erosion control can be wiped out in a single dust storm. Consequently these projects must be undertaken on a very large scale and with the aid of state and national agencies. One such measure is the planting of windbreaks, or *shelterbelts.* Extensive experiments have been conducted to find trees that can be planted at intervals to break the force of the wind. In addition to windbreaks, plants are needed to act as soil binders. Every inch of exposed land not used regularly for crop production must be anchored firmly by the roots of grasses and other soil-binding plants.

When land is cultivated, furrows should be *plowed at right angles to the prevailing wind.* Thus the wind does not blow down the furrows, but blows across them. Each furrow helps to stop the movement of soil. The effect is similar to that of contour plowing for water erosion. In sections where *irrigation* is possible, diversion of water into the fields during dry periods will check wind erosion because moist soil does not blow away.

Problems in administering soil conservation. In 1935 the United States Soil Conservation Service was established as part of the Soil Conservation Act. This agency became a permanent part of the Department of Agriculture. This division of the Department of Agriculture has embarked on an extensive program of soil conservation. Expert agricultural engineers are investigating all phases of the problem. They travel throughout the country, studying various problems and offering aid where needed.

Farmers have the opportunity to examine demonstration farms where soil conservation measures are in operation. If the farmers of a community wish to use these methods on their farms, they must first form a local soil conservation district under local control. Engineers from the Soil Conservation Service will then cooperate with the local district in applying soil conservation methods to the problem.

Soil problems and water problems – a vicious cycle. Disastrous floods and droughts, the two extremes in water problems, are inevitable results of misuse of soil and its plant cover. Rains that should soak into the ground and supply plant roots during drier periods run off the surface of eroded land in torrents. Streams flood with muddy water from nearby fields. Then there is too much water, but later in the season, plants may die for want of ground water that should have accumulated during the rainy period. During floods water washes soil away, and during droughts the wind blows it away. Soil erosion, floods, and droughts — these three disasters form a vicious cycle. Yet if we solve the soil problems, we will help correct the water problem. The wide flood plains of the streams and rivers of the Mississippi River drainage basin indicate that high and low water stages have always occurred. Rivers of this enormous system drain the land from the Appalachian Mountains in the east to the Continental Divide in the Rocky Mountains.

52-6 Irrigation ditches like this store water and make it available for crops at the time when it is most needed. (United States Department of Agriculture)

Prolonged droughts and desert conditions are normal in some sections of the country, too, because of uneven distribution of rainfall. But the past few generations are responsible for the mistakes that increased these natural conditions to the proportions of major disasters.

Depletion of ground water. The water table is lowering dangerously in many sections of the country, largely because of loss of water as runoff water during rainy periods and the increased use of ground water in cities. Numerous wells, necessary to supply drinking water, draw heavily on the supply of ground water. Industries require large quantities of water. Large cities must supplement their supply of ground water with treated surface water taken from rivers, lakes, and reservoirs.

In recent years cities have tapped the supply of ground water heavily in supplying cold water for air-conditioning systems. After the water has been used to remove the heat in buildings, it enters the sewer system and adds to the amount of surface water in rivers. It is not returned to the ground from which it was taken.

In an attempt to raise the level of ground water, the people in many areas of California have built dams to hold back the rainwater in natural basins. During the summer months the water is released slowly from these reservoirs and admitted to a series of ponds and gravel stream beds where it seeps into the ground. These ***percolation beds*** allow the water to maintain the water table level rather than flowing directly into the bays or oceans immediately after rains. In many communities of heavily populated Long Island, New York, street drains empty into dug basins, where the water seeps into the ground rather than running into salt-water bays, as it formerly did.

Runoff water. The water problem in America can never be solved until we have succeeded in reducing the amount of runoff water. To do this we must correct costly mistakes of the past and restore part of the original wilderness.

The following is what *should* happen when it rains. Rain that falls in level areas strikes the plant cover and drips to the surface of the soil. Most of the water that falls enters the soil and becomes ground water. Only when the soil is thoroughly soaked does it run off the surface or collect in pools.

In hilly and mountainous regions called ***watersheds***, some of the water soaks into the topsoil, protected by trees and other vegetation. Much of it follows rivulets that lead down the slope to streams. Streams in turn carry the water to rivers. As rivers rise, water overflows channels and spreads into flood plains. Much flood water is received by sloughs and backwaters. As the crest of the flood passes, the flood plains feed water back to the channel. With the end of the rainy season, water is maintained in the river by the sloughs and backwaters and by numerous springs that feed streams in the watersheds. Thus the ground and natural surface reservoirs receive excess water during rainy periods and maintain the water supply during dry periods.

This condition is altered somewhat in the Great Plains where there are no forests or tall grasses to help hold water back during brief but heavy rainy periods. Flash floods and some soil loss cannot be avoided in these regions, which explains why De Soto saw muddy flood water in the Mississippi River. Much of this mud came from the Great Plains region. Farther east the original tall grass prairies were dotted with sloughs and marshes during the rainy season.

But what *does* happen when it rains today? The spongy topsoil is gone in many regions. Rains pour onto hard subsoil clay, rush through deep gullies, and choke streams. In watersheds where forests have been cut away, nothing stops the rush of water downhill during flash floods. Rivers rise rapidly and have no place to store the excess water. Long ago we reclaimed their backwaters and swamps and extended our fields and cities to their very banks. Storm warnings go out and people flee from their lowland homes. Because much of our water supply roars to the sea, drought later in the season is in-

52-7 Check dams such as this one in California hold back rainwater in natural basins called percolation beds. (USDA)

evitable. River channels that were swollen with flood waters during the rainy period become narrow, winding trickles when the rain stops. Crops bake in the fields.

Water conservation. We can summarize the measures necessary to control floods and prevent seasonal droughts.

1. Control soil erosion and restore topsoil.
2. Restore forests, especially in watersheds.
3. Restore sloughs and backwaters along the rivers.
4. Prohibit cultivation of lowlands and flood plains of major rivers and restore the forests of these areas.
5. Build dams and reservoirs to hold back flood waters and store water for dry periods.
6. Control the use of ground water.
7. Maintain dikes and levees along major rivers. This measure, although the major flood control project in past years, is probably the least effective of all.

Dams and water power projects. As another means of controlling water, the government has constructed enormous dams in several sections of the country. These dams and the great reservoirs they form are important in preventing floods. In addition, they are the sites of hydroelectric plants, which use the water power of the dams to turn turbines attached to generators. In this way water power is converted into electricity for use in large areas of the nation. By raising the water level in the rivers, dams have made rivers navigable for long distances. In the West, water from reservoirs formed by dams is used for irrigation, and has made many semiarid regions ideal for crop production. Deep, clear lakes that lie above the dams are considered ideal recreation places for swimming, boating, and fishing and other aquatic sports.

IN CONCLUSION

A soaking rain is a welcome sight to a farmer whose crops are flourishing in fertile fields. But to a family fleeing the flood waters of a river on a rampage, the sight of more rain only adds to the misery. Man cannot destroy nature's balance without paying a terrible price, for almost every dust storm, advancing gully, and disastrous flood is related somehow to man's carelessness or indifference. The forces of nature are powerful. They can produce a rich harvest or tremendous destruction. They can provide us with great wealth or great poverty.

Conservation is everybody's business. No nation can prosper on poor soil. Our economy depends on agriculture, and agriculture is geared to the water cycle. In the next chapter, we will consider a job for everybody — forest and wildlife conservation.

BIOLOGICALLY SPEAKING

compost
contour farming
cover crop
crop rotation
depletion
gully erosion
humus
irrigation
leaching
peat
percolation bed
rill erosion
row crop
sheet erosion
shelterbelt
soil flora
strip cropping
subsoil
terracing
topsoil
watershed

QUESTIONS FOR REVIEW

1. What are the several forces in nature that crumble rock and form subsoil?
2. From what sources are humus and peat formed?
3. Give several examples of row crops and cover crops.
4. How did overproduction in past years lead to soil depletion?
5. How can deep plowing and cultivation cause leaching, especially in sandy areas?
6. What are various methods of restoring organic matter to soil?
7. How can rill erosion lead to gully erosion?
8. Why are row crops alternated with cover crops in strip cropping?
9. In what kind of situation would terracing be used?
10. What are two methods of stopping the advance of a large gully?
11. What various methods can be used to prevent wind erosion? Can these be used in all parts of the country, or are they adapted only to local situations?
12. List seven or more measures to reduce seasonal floods and prevent severe droughts.

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the various parts of topsoil and their importance to plant life.
2. Outline a crop rotation program, and explain why each crop is included.
3. How can loss of soil organic matter lead to the loss of another vital part of topsoil?
4. Discuss the combination of strip cropping, contour farming, and crop rotation in hilly agricultural areas.
5. Discuss various mistakes in past years which have led to disastrous floods and droughts. How do you think they might have been avoided?

CHAPTER 53

FOREST AND WILDLIFE CONSERVATION

Upsetting the natural balance. When the pioneers pushed westward through the North American wilderness, they found abundant wildlife at every turn. Inland waters teemed with fish, birds, and aquatic mammals. Large and small game roamed the forest and grassland. The woods bison, now extinct, lived in the forests as far east as New York State. Its western form, the plains bison, or buffalo, thundered across the grasslands in herds numbering tens of thousands. The white-tailed deer thrived on millions of acres of forest lands and supplied the early settlers with both meat and buckskin. The wildcat and cougar, or mountain lion, timber wolf and fox, beaver and muskrat, weasel and mink were some of the mammals of the wilderness.

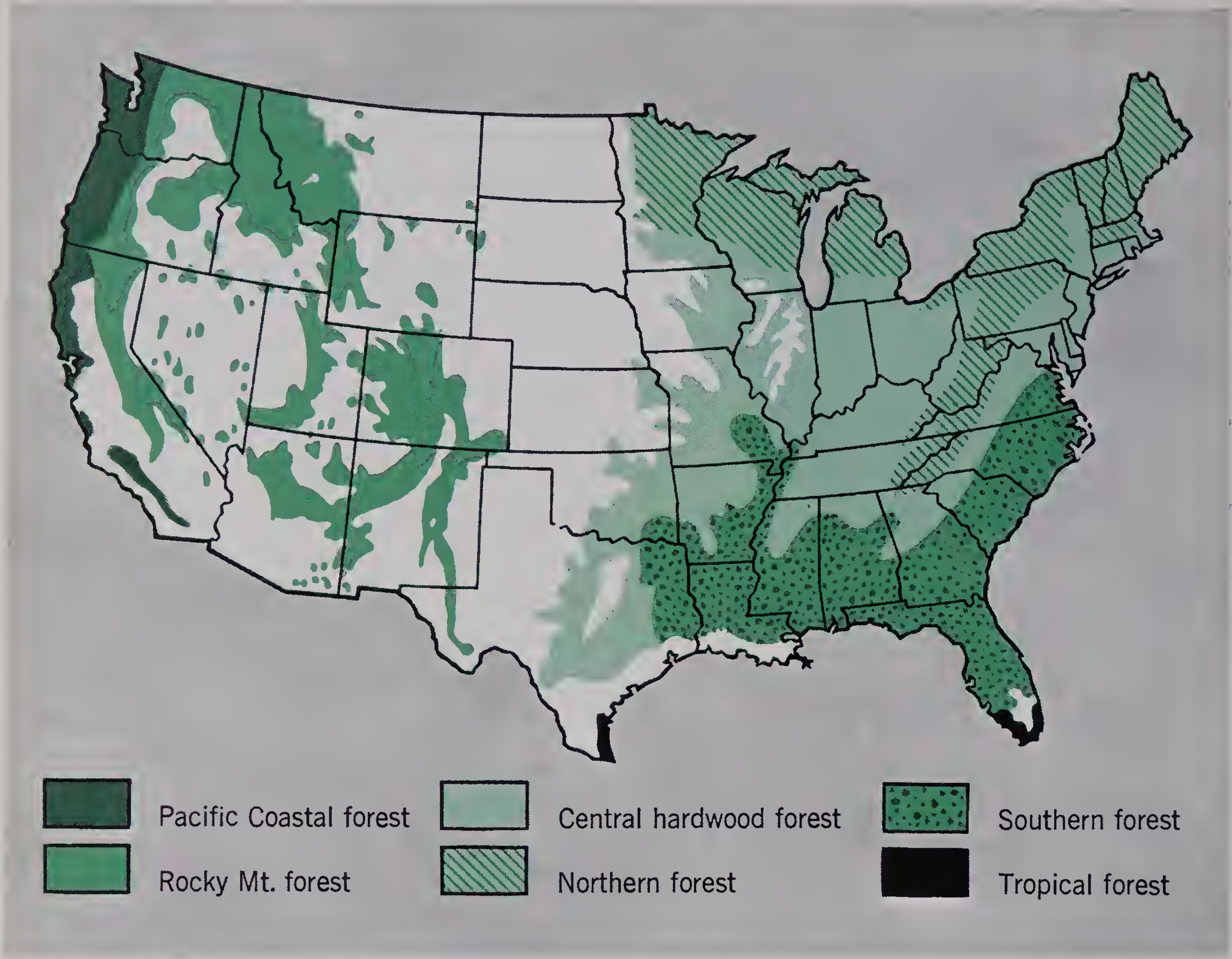
As the settlers began their conquest of the wilderness, wildlife began a slow retreat. Man learned to live in new environments, obtaining his needs from the plentiful supply. Large areas of forests were cleared and grasslands were plowed to raise crops to feed the people in the community. With the development of better transportation methods, man began to satisfy his wants by harvesting a surplus to be shipped and sold to other communities. As you have seen, the balance of life within a community is subject to the interactions of biotic and physical factors. The natural balance existing in many areas was further upset by man as he developed better rifles, more efficient lumbering machines and techniques, and better trapping devices.

Whether our forests will continue to meet our increasing demands and whether our wildlife will flourish in the last half of the 20th century will depend on what we have learned from the past, how well we understand ecological relationships, and our efforts to conserve our natural resources for future use.

Some forest facts. The original forests covered nearly half our land — a total of more than 822 million acres. Forests occupied the eastern and western parts of our country. Prairies, plains, and arid lands covered much of the large central area.

The two great forest belts of the East and West were in turn divided into distinct types of forests. Then as now, forests were greatly influenced by temperature, rainfall, soil, topography, and other physical factors of environment. Today all these same forests exist, although, for the most part, vigorous young second-growth and third-growth forests have replaced the original virgin stands. The nation's forest areas are shown in Fig. 53–1.

Forests – their use and misuse. More and more Americans are learning to re-



53-1 This map of the principal forest regions of the United States shows that almost one third of our land is occupied by forests.

gard forests as a crop. We are learning to harvest trees when mature and to leave seed sources to replace them as they are used. Our forest lands could have supplied all the timber required for building America without their being seriously depleted if they had been used wisely. Instead, they were destroyed by a rapidly growing nation that couldn't see the harm it was doing.

As early as 1905, officials in Washington, among them President Theodore Roosevelt, became alarmed about the critical condition of the forests. Accordingly Congress created the United States Forest Service under the control of the Department of Agriculture. When Theodore Roosevelt signed the act creating this agency on February 1, 1905, the forest conservation movement in America was begun. Vast tracts of timber, especially in the West, were set aside as national forests.

The United States Forest Service has built a splendid record through its years of activity. State and local agencies of conservation have looked to this agency for guidance and assistance in carrying out forest conservation programs. A staff of biologists highly trained in various specialties works untiringly in research laboratories in an effort to discover better conservation methods, controls for forest diseases, more efficient lumbering practices, and new uses for timber products. Even more remarkable are the changes that have come on privately owned forest lands. Since it has become possible to manage forests properly and still make a financial profit, forestry has been spreading rapidly. More professional foresters are hired by forest industries today than by the federal government. No small task in both the administration of the national forests and the management of millions of acres of private woodlands is the protection of these timberlands from fire.

Fire — the forest's worst enemy. In a recent year, 83,392 fires burned 3,409,038 acres of forest in the continental United States. This is a staggering loss to our nation. Fire protection has been extended to more and more forest areas in recent years, but there are still areas that lack organized fire protection.

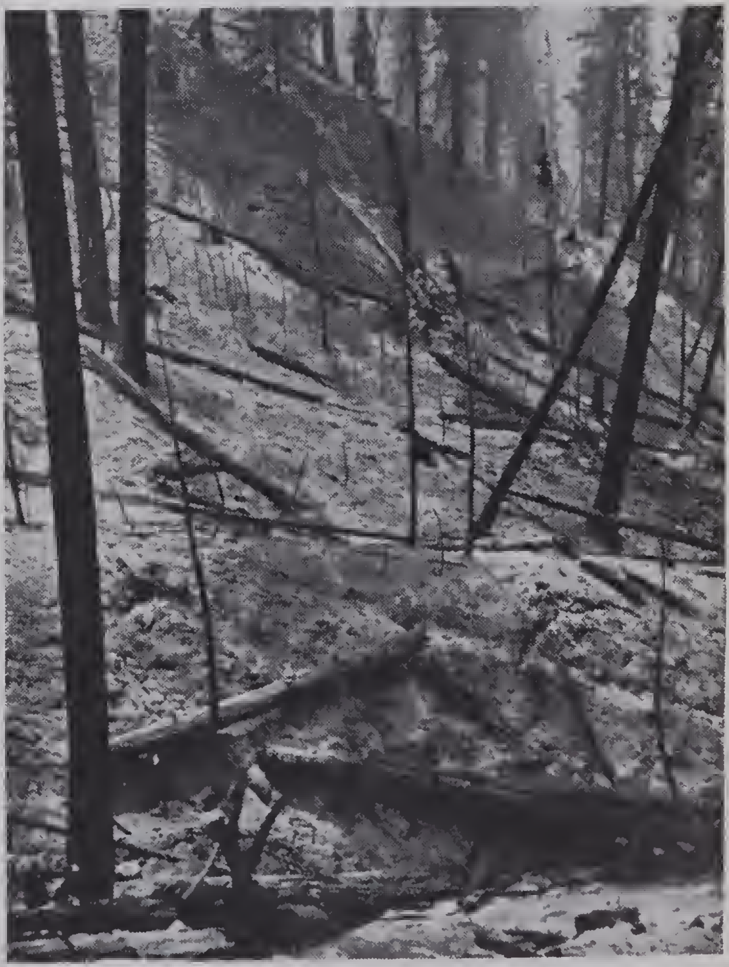
Aside from the danger to human life, a forest fire destroys standing timber and consumes the seeds and young trees of the future forest. A large fire may even burn into the rich humus of the forest floor. The large toll of animal life cannot be determined. Disaster continues as rains pour over the blackened earth and debris, washing the remaining humus into streams.

Causes of forest fires. According to reports of the United States Forest Service in recent years, the following are the most common causes of forest fires. The causes are listed in order of frequency:

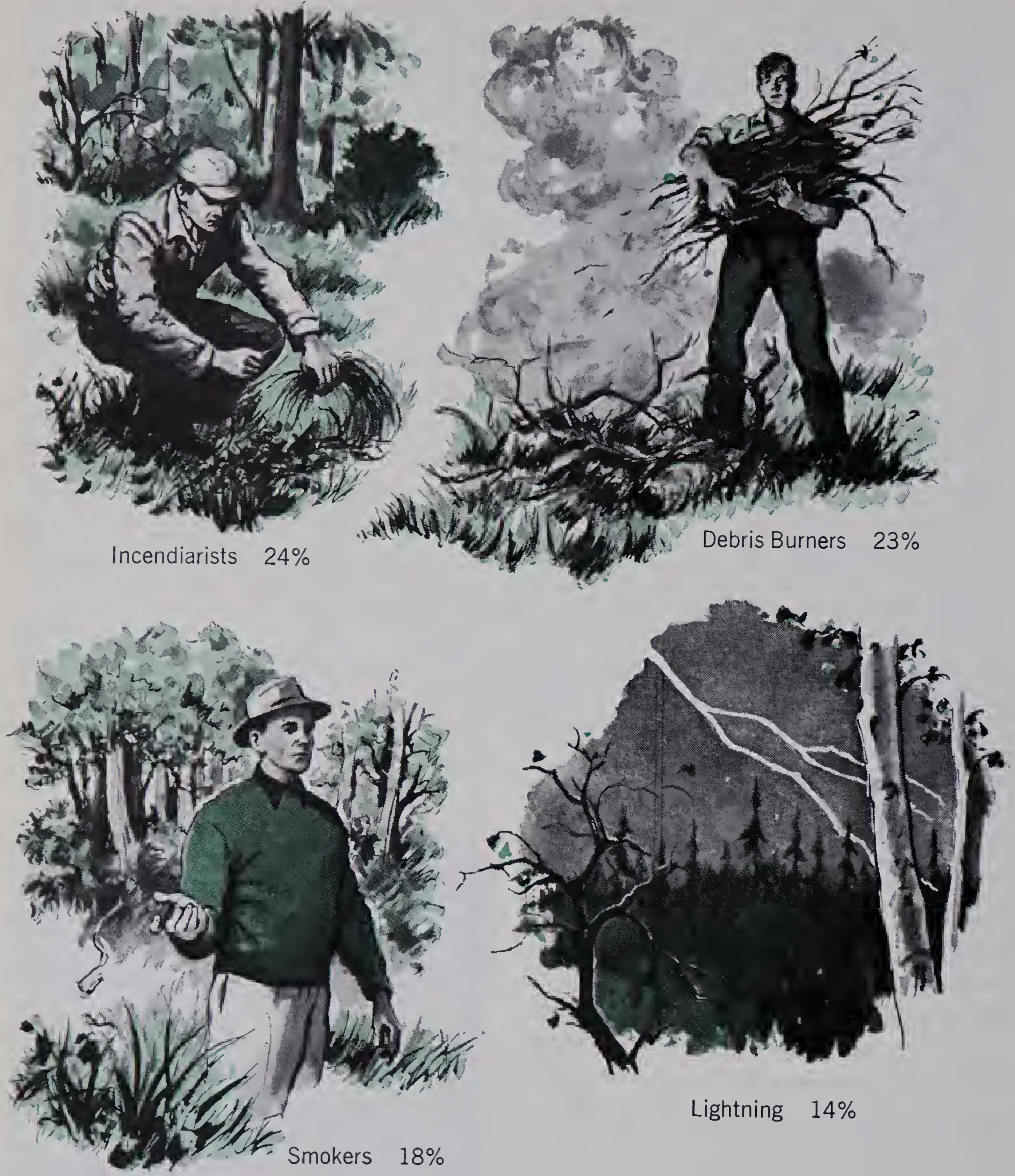
1. Incendiarists (those who set fires deliberately).
2. Debris burners (those who let brush fires get out of control).
3. Smokers (especially those who throw lighted cigarettes, cigars, and matches from automobiles).
4. Lightning.
5. Campers (especially those who leave live coals in a campfire).
6. Railroads.
7. Lumbering.
8. Miscellaneous.

It is shocking to learn that incendiarists are the leading cause of forest fires. Fires resulting from debris burners and smokers could be avoided if people were more careful and considerate of others. Lightning, the only natural cause, is responsible for less than 14 percent of the forest fires per year (Fig. 53–3).

Fire prevention. In protected forests, fire towers are placed at strategic points. Usually all areas of the forest are visible from at least two towers. Trained rangers survey the forest from the towers and report any evidence of fire to headquarters. A ranger cannot determine the exact distance of a fire from his tower, but he can report its direction. The same fire, spotted from another tower, will be reported from another angle. The point where the two lines of direction cross indicates the exact location of



53-2 Fire, whether caused by lightning or by man, is the forest's worst enemy. (U. S. Forest Service)



Incendiarists 24%

Debris Burners 23%

Smokers 18%

Lightning 14%

53-3 Note that fires from lightning are only a small percentage of the total causes of forest fires. (American Forest Products Industries, Inc.)

the fire. Fire fighters equipped with trucks, water tanks, and chemical fire extinguishers can often bring a fire under control before it becomes extensive. Fire lines, which resemble roads, penetrate the forest at regular intervals. They serve as avenues for reaching a fire and provide gaps at which a fire can be stopped. In some places, however, fires can be reached only by dropping fire-fighting crews from airplanes by parachute.

Our forests are protected from fire at a risk of many lives and at a cost of millions of dollars. It would seem a simple matter for all of us to cooperate in observing the following seven basic rules:

1. Never throw away lighted tobacco or matches.
2. Build campfires only in protected areas, and *put the fire out completely.*
3. Watch for fire while driving through a forest. If you see a small one, stop and put it out. If the fire is too large to extinguish by yourself, report it at once.
4. Report any suspicious person attempting to start a fire.
5. Never burn a field or debris close to a forest or without adequate help to keep the fire from spreading.
6. Become acquainted with your state's forest-fire laws.
7. Get to know your nearest fire warden or foresters.

Forest management. How valuable is a virgin forest? You may be surprised to learn that it is not as valuable as a planted and second-growth, managed forest. A virgin forest is always dominated by large, overripe trees. They have occupied their places for centuries — long past their period of rapid growth, and many of them are dying at the top. Some have been damaged by storms and are liable to attack by disease and insect pests. Much of the forest space is occupied by trees that have no commercial timber value. Other trees have grown crooked in their race for light. The floor of a virgin forest is littered with fallen trees in various stages of decomposition.

Compare this forest with a managed forest, operated on a ***sustained yield*** basis. A forest so planned will yield trees for cutting regularly. All the trees are valuable timber species. Weed trees, damaged trees, crowded trees, crooked trees, and diseased trees are removed in improvement cutting. As timber trees mature, they are removed by selective cutting. The forest is a source of constant revenue to the owner and yet is never cut extensively. Every inch of space produces good timber, and every tree is a nearly perfect specimen.

Today all national forests are using good cutting practices. Furthermore, the private owners who belong to the Tree Farm Program have pledged their cooperation.

Block cutting is another kind of lumbering used in stands of timber in which all the trees are about the same age. In such lumbering it is desirable to cut out a complete block and reseed it or replant it. In block cutting, stands of timber are left around the block for natural reseeding and protection of the exposed land. When small trees are established, another block can be cut. This method of lumbering is used in extensive stands of Douglas fir, and a modified method called strip cutting is used in harvesting of spruce.

Insect enemies. In our study of insects we mentioned the damage some of them cause to trees. The sawflies, bark beetles, spruce budworm, woodboring beetles, western pine beetle, white pine weevil, gypsy moth, hemlock looper, browntail moth, pine shoot moth, tent caterpillar, and tussock moth are among the worst forest pests. Sprays containing DDT and other powerful insecticides are effective against these pests. However, it is both difficult and undesirable to spray an extensive forest. As you learned in Chapter 32, in some areas where DDT has been used to kill mosquitoes, the death of many insect-eating fishes and birds has resulted. Studies have also revealed that widespread use of DDT has, by natural selection, been responsible for an increase in the number of insects resistant to the chemical.

53-4 Replanting is an important part of forestry management. With tractor and the tree planter it tows, two men can set up to ten times as many tree seedlings in one day as they can by hand. (American Forest Products Industries, Inc.)

We must depend principally on control of the forest insects by natural enemies. Birds are most valuable, although assistance is rendered by frogs, toads, snakes, ichneumon flies, and other insect destroyers.

Grazing and gnawing animals in forests. In many of the deciduous forest states, pasturing is the greatest forest enemy. Pasturing of cattle, horses, sheep, or hogs in wood lots will completely destroy the trees in time. First the animals eat or trample the young trees and reduce the woods to an open grove. Later they destroy the leaves on the lower limbs and injure roots and trunks. Aside from shelter, the animals receive very little value from a woods pasture. Trees and other plants of the forest are high in cellulose but very low in protein — an essential substance for the production of flesh and milk.

Effect of weather conditions on forests. Wind, ice, and snow are beyond our power to control. But damage done to forests by natural forces should receive attention. Broken limbs open a tree to attack by fungus diseases and insect pests. Forest litter resulting from ice storms creates a fire hazard.

Reforestation. The return of a forest from an open area is a slow process. Reforestation is a lengthy and costly process, but it is a vital part of the conservation program. Large sections, useless for agriculture, have been cleared unwisely in past years. These regions, as well as eroded, heavily lumbered, and burned-out areas, should be returned to trees as rapidly as possible.

The various forest states, the United States Forest Service, and many private lumber and paper companies maintain large nurseries where seedlings of timber species are grown. Private landowners of nearly 48 million acres of forest land in 45 states are growing trees as a crop in the Tree Farm Program. Some associations of wood-using industries now grow their own seedlings and give them free of charge to forest landowners in their operating areas. Pine is being used in reforestation of many hardwood forest regions because it matures rapidly and yields valuable construction lumber.

Lumber, our chief forest product. The greatest drain on the forests has been the demand for construction lumber. Once it was for log cabins and rail fences. Later it was lumber for frame buildings. Even in this age of brick and stone buildings, four out of every five houses are still made of wood. Regardless of the exterior building material, the average house uses 10,000 board feet of lumber for flooring, trim, window casings, and other wooden construction parts.

The evergreen forests supply most of the construction lumber today because of the fact that our commercial forests have always contained more softwoods than hardwoods and also because of the ease with which the soft wood of conifers can be worked. The most important native timber trees supplying lumber are in the table on page 730.

Newsprint for our daily paper. A single daily newspaper published in New York needs the paper produced from the ***pulpwood*** of 44 acres of timberland to print a single edition! When you consider the number of daily newspapers in the nation, the timber required for a day's supply of newsprint is almost staggering.

53-5 This is a log pond of a large mill whose output is devoted to paper. (American Forest Products Industries, Inc.)

In addition to newsprint, high quality book paper, stationery, packaging paper, toweling, and a great many other kinds of paper must be supplied daily.

Distillation products of lumber. Various hardwoods yield valuable products as a result of distillation. When certain kinds of wood are heated in closed iron cylinders, various products are given off as gases. By cooling, these gases are condensed into a variety of substances called ***distillation products.*** The wood turns black during distillation and becomes carbon or charcoal. The following are some of the products of hardwood distillation: wood alcohol, used as a solvent; acetic acid; lampblack, used in making certain inks; paints and varnishes; oxalic acid, used for dyeing and bleaching; and charcoal, used as a fuel and in water purification.

Beech, maple, and birch are commonly used in hardwood distillation.

For this reason, the distillation-industry centers are in Wisconsin, Michigan, Ohio, Pennsylvania, and New York.

Pine products. The South as a region leads the nation in the production of pine products. The fast-growing pines of the southeastern evergreen forest supply nearly two fifths of our nation's lumber. Nearly half the pulpwood used in making paper comes from this productive forest.

Turpentine, rosin, and pine tar are products of southern pines. When certain species of pine are tapped, they yield a large quantity of resin, a thick gummy sap. Resin is removed from the trees by cutting diagonal gashes through the bark into the wood, and is collected in jars or pots. When the resin is boiled, ***turpentine*** comes off as a gas. It is condensed to liquid form by cooling. After extraction of turpentine, tar and ***rosin*** remain. Rosin has many uses. You've probably seen a baseball pitcher reach for the rosin bag or a batter dust rosin onto the bat handle.

The sap of the sugar maple tree. Maple sugar is an important product of Vermont, New York, Ohio, and other states of the northern region of the deciduous forest. ***Maple sugar*** comes from the sap of the sugar maple tree, which is col-

IMPORTANT NATIVE TIMBER TREES

Name of Tree	*Forest Region*
Southern pine loblolly slash shortleaf longleaf	Southern forest
Douglas fir	Pacific coastal forest
Ponderosa pine	Rocky Mountain forest
Oak	Central hardwood forest
Hemlock (eastern and western)	Northern and Pacific coastal forest
Eastern white pine	Northern forest
Red gum	Central hardwood and southern forest
White fir	Rocky Mountain and Pacific coastal forest
Poplar	Central hardwood and southern forest
Maple	Northern forest and central hardwood forest
Redwood	Pacific coastal forest
Tupelo	Southern forest and central hardwood forest
Spruce	Northern forest
Cottonwood and aspen	Northern forest and Rocky Mountain forest
Cedar	Pacific coastal, northern, and southern forest
Sugar pine	Pacific coastal forest
Beech	Northern and central hardwood forest
Western larch	Rocky Mountain and Pacific coastal forest
Idaho white pine	Rocky Mountain and Pacific coastal forest
Cypress	Southern forest
Birch	Northern forest
Lodgepole pine	Rocky Mountain forest
Balsam fir	Northern forest

53-6 This worker is using an acid gun to stimulate resin flow from the new cut on the face of a pine tree that is being prepared for turpentining. (U. S. Forest Service)

lected in buckets attached to tapped trees in the early spring. The sap is boiled to remove the water until it becomes a thick syrup.

Tanning materials from bark. The tanning industry depends on the forests of the world for bark containing ***tannic acid,*** which is used in the tanning of hides. Chestnut wood, chestnut oak bark, eastern hemlock bark, and tanbark oak are the chief American sources. About 70 percent of the nation's tanning supply comes from foreign woods, however. The tanning industry is centered mostly in the lake states, Appalachian, and northeast forest regions.

Control of the water supply. The forest area acts like a sponge by absorbing the rainfall in its layers of humus. The leaves of trees keep the rain from falling directly on the soil and washing it away. The network of roots binds the soil, and the deep layers of humus hold water, so that there is a gradual runoff of soil water rather than a flash flood.

Forested land helps to control the water supply in the following ways:

1. Prevents floods and causes steady stream flow by reserve water held in humus.
2. Prevents spring freshets by shading snow so that it melts slowly.
3. Prevents drought by storing water in the wet season.
4. Prevents washing of soil into rivers.

Benefits to soil. The early settlers regarded the forests as an enemy to agriculture because clearing had to be done to make room for farms. But in a larger sense forests are a distinct benefit to soil. Erosion is one of the worst enemies of agriculture. But it is prevented by forests whose roots hold back the earth and whose leaves protect the surface. Furthermore, the humus which collects on the forest floor enriches the soil. In some areas the forest performs another function by preventing the spread of wind-blown sand over fertile areas, which are thus saved for use.

Effect of forests on climate. While the effect of forests on climate may not rank in importance with the two preceding benefits, it is certain that by their retention of moisture, forests modify the climate over large areas and apparently influence rainfall. To a lesser extent forests affect climate by giving protection from wind and sun.

Wildlife conservation. The term ***wildlife*** includes all native animals. The wildlife conservation program is concerned with those native animals that have a direct food, fur, or sporting value. After reading about the problems involved in wildlife conservation, you should be able to appreciate the value of scientifically based game laws.

Fish conservation. We often hear that a stream or a lake is "fished out." When the biologist studies such a lake, he is more likely to find that it is in reality overpopulated with thousands of stunted fishes so overcrowded that few can ever grow to a size worthwhile for fishermen. More rigid laws regulating fishing are not the solution; nor will restocking help in many cases for it has been established that with the exception of the trout species, most fishes maintain a maximum population in spite of man's fishing pressure. Give the fishes the proper environment and they will hold their own and even increase in heavily fished streams and lakes.

In the study of fish conservation we must first find out the characteristics of productive waters. Then we shall consider various practices that destroy fishes and make waters unproductive. Finally we shall discuss conservation measures that can restore ideal habitats and return the fishes to our waters.

Characteristics of a productive lake and stream. A lake that supports a thriving fish population must supply many different environments suitable for large species and smaller ones, frogs, insects, and other vital parts of a complicated society and food chain. Deep channels and holes are necessary to protect fishes during both the cold of winter and the extreme heat of summer. The depth at which fishes live varies greatly with water temperature. During the spawning season, sunfish, bass, and many other species leave the deep water and enter clear, shallow pools and backwaters. Here the *fry* hatch and live protected by water plants in shallow areas.

53-7 Fish ladders are built around large hydroelectric dams to enable fish to travel upstream during the spawning season. (Union Pacific Railroad)

Protozoans, tiny crustaceans, and larvae of various insects supply food necessary for small fishes. As the smaller fishes leave the shallow water and enter deep water, they become food for predatory *game fishes* such as the bass, pike, trout, and perch. *Forage fishes,* including such species as shiners, chubs, and other minnows, while they have no sport or food value for man, are vital as a food for the game fishes.

The productive stream has rapids and riffles, shallows and depths, channels and undercut banks. Larger rivers are fed from productive backwaters. Fallen logs and driftwood provide ideal habitats for many species. Abundant water plants are necessary to provide food for vegetarian fishes and other aquatic animals, and supply the organic matter required by bacteria, protozoans, and organisms essential in the food chain.

Destruction of aquatic habitats. Many practices, some careless and others deliberate, have destroyed aquatic habitats. In regions where the water table has been lowered by removal of vegetation, soil erosion, and other misuse of the land and water resources, the level of lakes and ponds has fallen. Small ponds may dry up completely during the summer. The water in larger lakes may recede to the point that shallow areas and backwaters are left dry, thus destroying both spawning areas and regions where much of the food supply develops. Many backwaters and marshes have been drained deliberately because they were thought to be useless.

The channels of many rivers have been dredged and straightened to increase the flow of water. Such open channels may be good from the standpoint of flood control, but they are not good surroundings for fishes. Fishes thrive better in a river with natural bends, rapids, and deep pools.

Dams across rivers interfere with fish migrations unless fish ladders are provided. A ***fish ladder*** is a channel around a dam through which fish can travel upstream. The fast flow of water is broken by a series of staggered plates projecting into the water from the sides. In other fish ladders a long slope is broken into a series of steps like terraces, which can be leaped by fish traveling upstream.

Serious floods are tragic, not only to man but also to fishes and aquatic animals. When flood waters overflow the lowlands, many fishes follow the rising water. Large numbers are left stranded in isolated pools when the waters recede.

Water unfit for fish. Many game fishes cannot survive in water containing a large amount of mud and silt. Mud coats the surface of the gill filaments and prevents oxygen from reaching the

53-8 The shad shown here could not survive because of the pollution of their stream by sewage. (U. S. Fish & Wildlife Service) blood stream. This type of suffocation is common in species with a high oxygen requirement.

Sewage, garbage, cannery waste, and other organic refuse dumped into water kill fishes for another reason. Organic matter decays in water as a result of bacterial action. Oxygen is used up during this process, and fish die for want of it in the water.

Industrial and chemical wastes poured into streams poison fishes and other aquatic animals. Cyanide, acids, alkalies, and other industrial wastes may affect the stream's inhabitants for many miles downstream.

Indiscriminate stocking. One of the most difficult problems facing fishery biologists today is the result of introducing new species to waters in times past. Often the new species crowded out the more desirable native fishes. In the Northeast many beautiful trout lakes have been completely taken over by stunted yellow perch and golden shiners that were introduced 50 years or more ago.

Where possible lakes that have been overrun by undesirable fishes are being completely drained for a period of time to kill the fishes. Other lakes are poisoned. Then these reclaimed lakes are restocked with the species that were present before man attempted to improve them. Thus many waters have been returned to the public.

Hatchery programs. Both state and federal fish hatcheries produce large numbers of game fishes in their rearing ponds. The hatcheries maintain a stock of adult breeders kept in special spawning pools. After spawning, the breeder fishes are removed to prevent destruction of the small fishes. Fry hatched in late spring reach stocking size by midsummer or early fall. Many hatcheries use special trucks equipped with aerated tanks for transporting small fishes to distant streams and lakes.

Artificial propagation and stocking are essential parts of fish conservation programs. However, it is useless to stock polluted waters, or those that lack conditions necessary to supply adequate food, or those that are already overpopulated.

Private rearing ponds and lakes. Many farmers have constructed earthen ponds in low corners of fields by building up banks. These *farm ponds* are stocked with crappies, bluegills, catfish, and other species. The pond provides recreation, conserves water, helps prevent soil erosion, provides a reserve for fire protection, and supplies many strings of fish for the dinner table.

Farm pond fish populations must be managed just as carefully as the cattle, pigs, or chickens reared on the farm. To be continually productive, such a pond must be periodically fertilized and adequately harvested. Otherwise the fish population will almost certainly eventually deteriorate to thousands of fishes too small to be eaten.

Great numbers of artificial lakes have been made by building dams and backing up water in valleys. Lakes of this type are ideal for fishing and boating.

Useless destruction of valuable allies, the birds. The advancing tide of civilization has made dangerous inroads into the populations of songbirds and game birds. Much of this destruction is useless and avoidable.

The cutting of forests, clearing of underbrush, and burning of fields have removed vast areas of bird habitats. Unnecessary drainage of marshes and lowering of the water in ponds and lakes have deprived water birds and wading birds of both food and nesting sites.

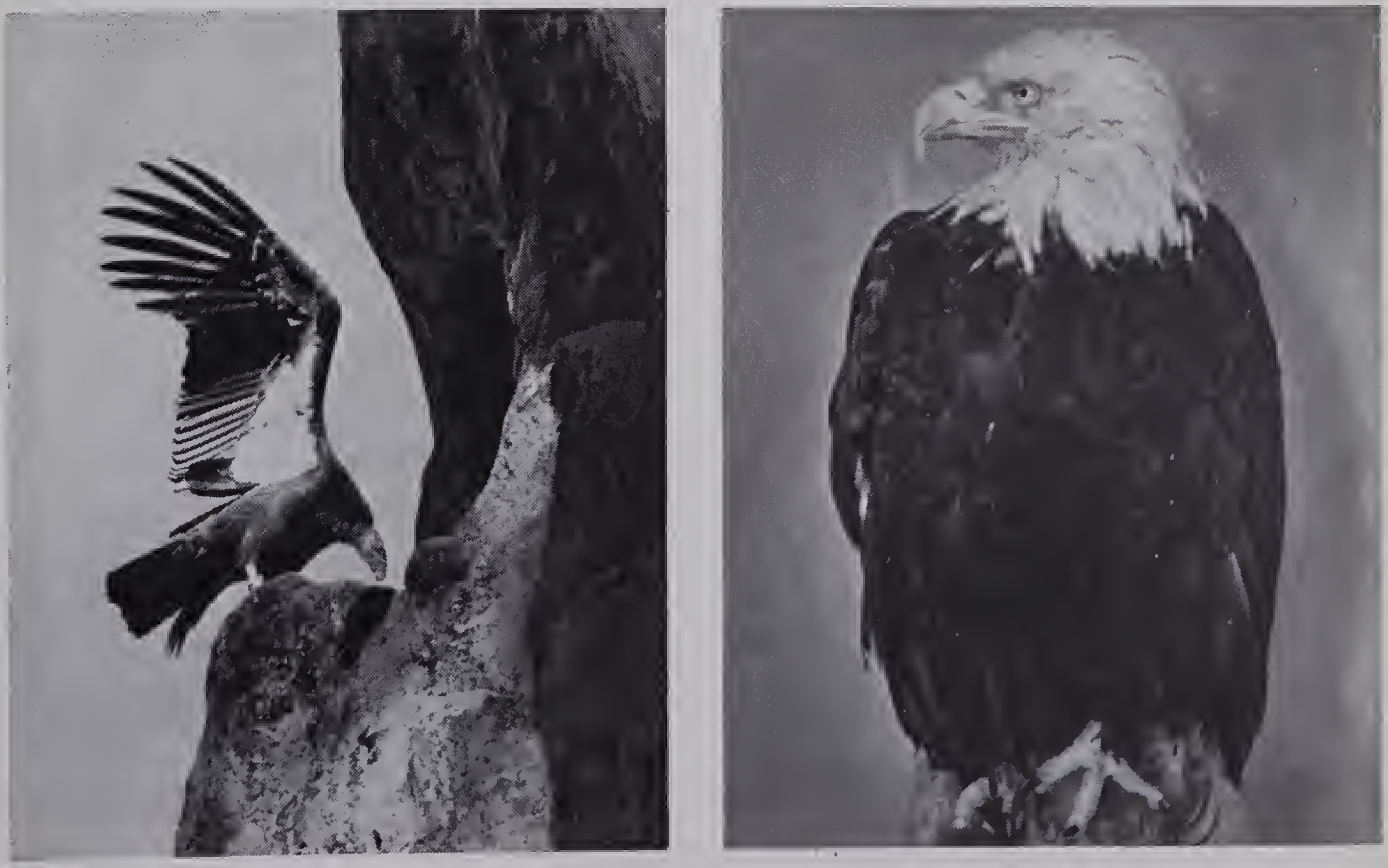
In former years many thousands of birds were slaughtered for flesh or feathers. Fortunately such market hunting is forbidden now, both by federal and state laws. But conservation measures came too late to save some species that were once common but are now extinct.

In the early 1800's Audubon described flocks of passenger pigeons so large they darkened the sky. When such flocks settled in trees to roost for the night, their enormous weight bent the branches and sent many crashing to the ground. We have reports of pigeon hunters who climbed the trees and knocked thousands of pigeons from their perches with clubs. Thousands of others were gathered in sacks to be sold for a few cents each or left on the ground as food for hogs. The last survivor of what is estimated to have been over two billion passenger pigeons died in the Cincinnati zoo in 1914. What caused the complete extermination of this valuable bird in less than 100 years? No simple explanation can be found. Market hunting took a heavy toll, as did the removal of large areas of the birds' food supply. But these alone could not have accounted for the extermination of such an abundant species. The introduction of an epidemic disease may have been a contributing factor. Certainly no thought was given to conservation until too late.

Rare birds we may still save. Bird societies are watching several other species which are nearing extermination but which may still be saved.

Only a few ivory-billed woodpeckers remain in the forests of river bottoms in the South. Anyone seeing one of these rare birds should report it at once to the National Audubon Society.

The whooping crane is disappearing from the region of the Great Plains.



53-9 The California condor on the left and the northern bald eagle on the right are both nearing extinction. (Left: Kofard from National Audubon Society; right: Ambler from National Audubon Society)

53-10 The ring-necked pheasant is a game bird that needs to be protected. (USDA)

In a recent count, only 26 adult whooping cranes were found. These were in the Aransas, Texas, National Wildlife Refuge, their wintering grounds.

The prairie chicken was hunted widely for market in earlier times. More recently its numbers have been further reduced by the plowing of native grasslands in the prairie states.

The California condor, a type of vulture, is a rare species of the mountainous regions of the Far West. Less than 100 of these great birds are left. The condor, with a body three feet long and wing spread of ten feet or more, lives on decaying flesh. Lack of food and the fact that it lays only one or two eggs each season may bring about its extinction.

The eastern bluebird, which is sometimes seen around settled areas and farms, has been declining in numbers for years. This pretty little songbird may disappear in your lifetime.

Problems relating to game birds. Migratory ducks and geese have been favorite *game birds* for hunters. But the decline in their populations during the past 50 years has been due only partially to hunters. The draining of marshes, which supply natural food such as wild rice as well as nesting places and cover, has presented a serious problem in conserving these birds. Large numbers of ducks die of alkali poisoning on ponds and lakes of the western prairies when the water is low and salts become concentrated. In some regions thousands of ducks and geese have died of botulism when they consumed the deadly toxin while probing for food in the mud of ponds and lakes at low water.

Upland game birds, including the quail, partridge, grouse, wild turkey, and pheasant, are widely hunted by sportsmen. They can survive regulated hunting only if adequate food and cover are provided, especially during winter months. Many farmers allow trees, shrubs, and tall grass to grow along their fence rows and roadsides as cover. A few rows of grain left at the margin of fields provides winter food for these and other birds. Boy Scouts, 4–H Clubs, sportsmens' clubs, and many individuals place grain in woods and fields to help game birds get through the difficult winter months.

Private agencies work closely with the Fish and Wildlife Service, a branch of the United States Department of the Interior. This important bureau has charge of the conservation of birds and other animals, controls the national wildlife reservations, administers laws regarding commerce in game, and publishes many educational bulletins and other information.

Destruction of fur-bearing animals. The first drain on the mammal population of North America occurred early in our history. Long before the pioneers began their journey westward, trappers had explored the wilderness in search of fur-bearing animals, and fur traders were buying pelts from the Indians. As long ago as 150 years, trappers and fur traders were penetrating the forests of the Pacific Northwest. Their prize was the beaver, highly valued in the eastern and European markets. "Empire builder" is an appropriate name for this valuable fur-bearer, which played a major role in the settlement of this vast wilderness country. Fortunes were made in the fur business during these times. The pelts of beaver, mink, otter, muskrat, fox, skunk, and other fur-bearers brought an annual revenue of over $100,000,000. Early trappers were very ruthless hunters. They gave no thought to conservation of the animals they sought. The numbers of fur-bearing animals decreased rapidly. Later the settlers began clearing and cultivating the land. Only in the most remote wilderness areas were the fur-bearers able to survive unmolested.

Destruction of larger mammals. The slaughter of the plains bison is a story of useless waste. In the middle of the last century herds of bison numbering many thousands thundered across the Great Plains. For centuries this noble animal had supplied both flesh and hides to plains Indians. But as calves replaced the mature animals taken from the herds by hunting, both the Indians and the bison flourished. Then came the buffalo hunters. Bison were slaughtered

53-11 The mink on the left and the gray fox on the right are both fur-bearing mammals which are so rare in nature that they are raised in great numbers on fur farms. (Left: Morton from National Audubon Society; right: Maslowski from National Audubon Society)

53-12 The American bison is now protected on large game preserves and its numbers are slowly increasing. (Bureau of Land Management)

in tremendous numbers as food for workmen building railroads through the West or for pure sport. At one time passengers on trains amused themselves by firing at bison from open platforms. Thousands were killed for buffalo robes and the carcasses were left to rot. It is shocking to learn that great numbers of bison were killed deliberately to starve the plains Indians into submission. Within 50 years bison herds were reduced from tens of thousands to mere remnants. At one time it appeared likely that the bison might die out entirely.

The white-tailed deer and black bear vanished from the remaining forests of most of the central and eastern agricultural states. Elk, mule deer, and antelope were slaughtered in the West.

What did the destruction of so much of the game resources profit America? It supported a rich fur trade for a time, and it provided food and clothing to pioneer families. But this could have been accomplished by sacrificing only a small portion of wildlife population. Much of the destruction of wildlife was useless, careless waste.

Wildlife restoration. Most small mammal and big-game mammal species have survived in greatly reduced numbers in the remaining wilderness regions. Can they return with our help to at least a portion of their former ranges? Can we make room for them among our many farms and ranches with their enormous population of domestic animals? This will require careful planning and scientific management. But it can be done.

There are already some dramatic examples of wildlife restoration. Because of wise management and the adaptability of the animal, the white-tailed deer population is now larger than it was before the arrival of civilized man. In Pennsylvania after the turn of the century, there were so few deer that stock was brought in from other states. Today the Pennsylvania deer herd is so large that thousands die of starvation each winter — in spite of tremendous hunting pressure.

The wild turkey is a similar example of restoration through effective management. Once common throughout the Northeast, wild turkeys became nearly extinct in all but a few southern states. Today turkeys have been restored to much of their former habitat. The greatest problem in restoring turkeys was obtaining stocks of truly wild birds, for wild turkeys will not mate in captivity. The big breakthrough came when the manager of a Pennsylvania game farm discovered that if wing-clipped hen turkeys were kept in a fenced area, the wild toms would fly in to mate and would then leave. Systematic harvesting of eggs then became a relatively simple matter.

National parks and national forests. The 29 national parks with their six million acres of forest are to be preserved forever. They are part of preserves and recreational areas dedicated to those who seek undisturbed and unspoiled natural beauty.

In addition there are 149 national forests covering more than 181 million acres. The national forests supply timber for about 12 percent of the nation's forest products. In addition they supply homes for wildlife and aid greatly in restoring birds and animals that have been reduced in number in past years. During summer months, when drought strikes the Great Plains, they are opened to cattle and sheep as grazing areas under supervision. In addition, they provide recreational areas attracting campers and sportsmen who fish in their lakes and streams.

IN CONCLUSION

The forests and wildlife of America belong to you. What you do to preserve them will be your contribution to future generations. If you live on a farm or a ranch, think of the birds and animals along your fence rows or in the brush and woodland that you have not cultivated. If you are one of the many city dwellers, protect the squirrels in the park and the rabbits in the vacant lot. Do not leave litter around. If you fish and hunt, respect the laws and limits. Be sure your campfire is really out. The fewer signs of human presence you leave behind you in a natural area, the more you are doing to maintain the beauty of America.

Have you thought of joining the Audubon Society or the Wilson Club? Have you heard of the Isaak Walton League? These organizations would welcome you if you are interested in wildlife and conservation. Ducks Unlimited, The National Wildlife Federation, and The American Wildlife Institute are other civilian agencies carrying on important work. They deserve your full support and cooperation.

BIOLOGICALLY SPEAKING

distillation products
farm pond
fish ladder
forage fish
fry
game bird
game fish
maple sugar
pulpwood
rosin
sustained yield
tannic acid
turpentine
wildlife

QUESTIONS FOR REVIEW

1. What are the various causes of forest fires? Indicate which ones are deliberate, the result of carelessness, or unavoidable. How can forest fires be prevented?
2. How can two forest rangers, viewing a fire from towers, pinpoint the location of the fire?
3. List several of the worst insect enemies of forest trees.
4. What types of trees are removed from a managed forest during improvement cutting?
5. Under what conditions are whole sections of a forest cleared by block cutting?
6. Name several products of the distillation of hardwoods.
7. List the principal products of pine resin. What forest region supplies nearly all of these products?
8. What are some of the trees that supply bark for the tanning industry?
9. What are some features of a productive river or stream?
10. How has lowering of the water table caused serious loss of fish even in bodies of water that do not dry out?
11. Describe the operation of a fish ladder around a dam.
12. How are farm ponds made?
13. Make a list of bird species that are now very rare or nearly extinct.

APPLYING PRINCIPLES AND CONCEPTS

1. Discuss the scientifically managed forest operated on a sustained yield basis, and show how this forest is more productive than a virgin forest.
2. Discuss the role of sportsmen in the wildlife conservation program.
3. List various problems in restoring big-game mammals in the agricultural states.
4. Why are predatory birds and animals essential to proper game management?

RELATED READING

Books

Archer, Sellers. *Rain, Rivers and Reservoirs: The Challenge of Running Water.* Coward-McCann Inc., New York. 1963

Bates, Marston. *Animal Worlds.* Random House, Inc., New York. 1963

Bates, Marston. *Man in Nature.* Prentice-Hall, Inc., Englewood Cliffs, N. J. 1961

Bates, Marston. *The Forest and the Sea.* Mentor Books, New York. 1959

Bear, Firman. *Earth: The Stuff of Life.* University of Oklahoma Press, Norman, Okla. 1961

Berrill, Jacqueline. *Wonders of the Woods and Deserts at Night.* Dodd, Mead and Co., Inc., New York. 1963

Brown, Vinson and others. *Common Wildlife of the Southwest Deserts.* Naturegraph Co., Healdsburg, Calif. 1964

Buchsbaum, Ralph and Buchsbaum, Mildred. *Basic Ecology.* Boxwood Press, Pittsburgh, Pa. 1957

Carthy, J. D. *Animal Navigation.* Charles Scribner's Sons, New York. 1963

Christian, Garth. *While Some Trees Stand: Wildlife in Our Vanishing Countryside.* Transatlantic Arts, Hollywood-By-The-Sea, Fla. 1964

Dasmann, Raymond F. *The Last Horizon.* The Macmillan Co., Chicago. 1963

Farb, Peter and the Editors of Life. *Ecology.* Time, Inc., Chicago. 1964

Farb, Peter and the Editors of Life. *The Forest.* Time, Inc., New York. 1961

Friendly, Natalie. *Wildlife Teams.* Prentice-Hall, Inc., Englewood Cliffs, N. J. 1963

Gleason, Henry A. and Cronquist, Arthur. *Plant Dominions, U.S.A.* Columbia University Press, New York. 1964

Gleason, Henry A. and Cronquist, Arthur. *The Natural Geography of Plants.* Columbia University Press, New York. 1964

Hitch, Allen S. and Sorenson, Marian. *Conservation and You.* D. Van Nostrand Co., Inc., New York. 1964

Idyll, C. P. *Abyss: The Deep Sea and the Creatures Who Live in It.* Thomas Y. Crowell Co., New York. 1964

Leopold, A. Starker and Editors of Life. *The Desert.* Time, Inc., New York. 1961

Milne, Lorus J. and Milne, Margery. *The Balance of Nature.* Alfred A. Knopf, Inc., New York. 1960

Odum, Eugene P. and Odum, Howard T. *Fundamentals of Ecology,* 2nd Ed. W. B. Saunders Co., Philadelphia. 1959

Peterson, Roger Tory and Fisher, James. *Wild America.* Houghton Mifflin Co., Boston. 1960

Sollers, Allen. *Ours Is the Earth: Appraising Natural Resources and Conservation.* Holt, Rinehart and Winston, Inc., New York. 1963

Udall, Stewart L. *The Quiet Crisis.* Holt, Rinehart and Winston, Inc., New York. 1964

Articles

Deevey, E. W. "Life in the Depths of a Pond." *Scientific American.* October, 1951

Dietz, Robert S. "The Sea's Deep Scattering Layers." *Scientific American.* August, 1962

Llano, George A. "The Terrestrial Life of the Antarctic." *Scientific American.* September, 1962

Murphy, Robert Cushman. "The Oceanic Life of the Antarctic." *Scientific American.* September, 1962

Opik, Ernest J. "Climate and the Changing Sun." *Scientific American.* June, 1958

Woodwell, George M. "The Ecological Effects of Radiation." *Scientific American.* June, 1963

APPENDIX

SOME SPECIALIZED BRANCHES OF BIOLOGY

ANATOMY	Study of the gross structure of plant and animal organs
BACTERIOLOGY	Study of microscopic nongreen protists, some of which cause disease
CYTOLOGY	Study of the structure and functions of cells
ECOLOGY	Study of the environmental relations and distribution of organisms
EMBRYOLOGY	Study of the early development of organisms
ENTOMOLOGY	Study of insects
EUGENICS	Branch of genetics dealing with human heredity
GENETICS	Study of heredity
HERPETOLOGY	Study of reptiles
HISTOLOGY	Study of the structure of tissues
ICHTHYOLOGY	Study of fish
MORPHOLOGY	Study of total structure of organisms
MYCOLOGY	Study of fungi
ORNITHOLOGY	Study of birds
PALEONTOLOGY	Study of the life of past geological periods
PARASITOLOGY	Study of organisms which live on or in the bodies of other organisms and derive their nourishment from that organism
PATHOLOGY	Study of diseases of organisms
PHYCOLOGY	Study of algae
PHYSIOLOGY	Study of the functions of organisms
PROTOZOOLOGY	Study of protozoans
SPACE BIOLOGY	Study of survival problems of living things in outer space
TAXONOMY	Naming, grouping, and classifying of organisms
VIROLOGY	Study of viruses

A MODERN CLASSIFICATION OF ORGANISMS

KINGDOM PROTISTA

Organisms having a simple structure; many unicellular, others colonial or multicellular, but lacking in specialized tissue; both heterotrophic and autotrophic; neither distinctly plant nor animal.

PHYLUM SCHIZOMYCOPHYTA (SCHIZOPHYTA)

Mostly parasitic or saprophytic organisms; cells lacking an organized nucleus, with nucleoproteins in contact with cytoplasm; reproduction by fission, certain forms producing endospores: bacteria, Rickettsiae, actinomycetes, spirochetes [placed in Kingdom MONERA in certain classifications].

PHYLUM CYANOPHYTA

Cells containing chlorophyll and other pigments not localized in plastids; cells lacking an organized nucleus, with nucleoproteins in contact with cytoplasm; reproduction by fission and spores: blue-green algae (*Nostoc, Anabaena, Gloeocapsa, Oscillatoria*) [placed in Kingdom MONERA in certain classifications].

PHYLUM CHLOROPHYTA

Cells containing chlorophyll and other pigments localized in plastids; food stored as starch; cells with organized nucleus; unicellular, colonial, and filamentous forms; motile, free-floating, and sessile: green algae (*Spirogyra, Protococcus, Chlorella,* desmids, *Ulothrix, Oedogonium*).

PHYLUM CHRYSOPHYTA

Cells containing chlorophyll and other pigments localized in plastids; cells often yellow-green, golden-brown, or brown in color; food stored as oil and complex carbohydrates; cell walls often containing silicon; unicellular, colonial, and filamentous forms; motile and free-floating: yellow-green algae, diatoms.

PHYLUM PYRROPHYTA

Cells containing chlorophyll and other pigments localized in plastids; cells often yellow-green or golden-brown; food stored as starch or oil; unicellular flagellates with two flagella, one lateral and one longitudinal; mostly marine organisms: dinoflagellates, cryptomonads.

PHYLUM PHAEOPHYTA

Cells containing chlorophyll usually masked by a brown pigment, localized in plastids; food stored as oil and complex carbohydrates; multicellular; nonmotile; plant body usually large, complex, and sessile; mostly marine organisms living in shallow water: brown algae (*Fucus, Sargassum, Nereocystis*).

PHYLUM RHODOPHYTA

Cells containing chlorophyll usually masked by a red pigment, localized in plastids; food stored as a carbohydrate related to starch; multicellular; nonmotile; plant body complex, usually sessile; mostly marine, deep-water organisms: red algae (*Chondrus, Gelidium, Polysiphonia*).

PHYLUM MYCOPHYTA (EUMYCOPHYTA)

Organisms lacking chlorophyll; parasitic and saprophytic: true fungi.

Class Phycomycetes: Algalike fungi: black molds (*Rhizopus*), water mold (*Saprolegnia*), white "rust," downy mildews.
Class Ascomycetes: Sac fungi, usually producing eight ascospores in an ascus; many forms producing conidiospores: blue and green molds (*Penicillium, Aspergillus*), morels, yeasts, cup fungi, powdery mildews.
Class Basidiomycetes: Basidium (club) fungi: rusts, smuts, mushrooms, puffballs, bracket fungi.
Class Deuteromycetes: Imperfect fungi: ringworm fungi; thrush (*Candida*), athlete's foot fungus.

PHYLUM MYXOMYCOPHYTA

Amorphous slimy growths consisting of a naked protoplasmic mass creeping slowly by a flowing, amoeboid motion; mostly saprophytes; spores produced in sporangia: slime fungi (slime molds).

PHYLUM SARCODINA

Organisms forming pseudopodia; pellicle at cell surface lacking; reproduction principally by fission; fresh-water and marine: amoeboid organisms (*Ameba, Endameba, Arcella*), foraminifers, radiolarians.

PHYLUM MASTIGOPHORA

Organisms that propel themselves with one or more flagella; pellicle usually present; fission longitudinal; flagellates (*Euglena, Trypanosoma, Volvox, Leishmania*).

PHYLUM CILIOPHORA (CILIATA)

Locomotion by means of cilia; pellicle present; many forms with macronucleus and micronucleus: ciliates (*Paramecium, Vorticella, Stentor, Stylonychia*).

PHYLUM SPOROZOA

No structures for locomotion; spore-forming; all parasitic: sporozoans (*Plasmodium*).

KINGDOM PLANTAE

Multicellular plants having tissues and organs; cell walls containing cellulose; chlorophyll *a* and *b* present and localized in plastids; food stored as starch; cell walls containing cellulose; sex organs multicellular; autotrophic.

PHYLUM BRYOPHYTA

Multicellular green plants living on land, usually in moist situations; alternation of generations with the gametophyte the conspicuous generation; vascular tissues lacking; reproduction by spores and gametes.

Class Hepaticae: Gametophyte leafy or thalluslike, usually prostrate: liverworts (*Marcantia, Riccia*).

Class Anthocerotae: Gametophyte thalluslike, sporophyte elongated and cylindrical: hornworts.

Class Musci: Gametophyte usually an erect leafy shoot, sporophyte inconspicuous and parasitic on the gametophyte: true mosses (*Polytrichium, Sphagnum*).

PHYLUM TRACHEOPHYTA

Plants with vascular tissues; sporophyte plant body prominent; highly specialized roots, stems, leaves, and reproductive organs in most forms.

SUBPHYLUM PSILOPSIDA: Leaves usually absent, if present small and simple; roots absent; mostly fossils (only four living species): *Psilotum, Tmesipteris.*

SUBPHYLUM LYCOPSIDA: Leaves simple and usually small, spirally arranged on stem: club mosses (*Lycopodium, Selaginella*).

SUBPHYLUM SPHENOPSIDA: Leaves small and simple and arranged in whorls; mostly fossils: horsetails (*Equisetum*).

SUBPHYLUM PTEROPSIDA: Leaves usually large and complex; plant body often large.

Class Filicineae: Sporophyte producing a leafy frond, usually bearing sporangia; rhizome usually creeping; gametophyte plant body a small prothallium: ferns and tree ferns.

Class Gymnospermae: Seeds not enclosed in an ovary; mostly large, woody plants; many evergreen.

Order Cycadales: Primitive fernlike gymnosperms: cycads or sago palms (*Cycas, Dioon, Zamia*).

Order Ginkgoales: Large trees with two kinds of branches, one bearing most of the wedge-shaped leaves in clusters; mostly fossils (one genus and species remaining): *Ginkgo biloba.*

Order Coniferales: Cone-bearing gymnosperms, mostly evergreen; leaves in the form of needles or scales: pines, cedars, spruces, firs, larches, yews.

Order Gnetales: Possible forerunners of the flowering plants; two seed leaves on the embryo; wood containing vessels; mostly fossils (only three remaining genera): *Ephedra, Welwitschia, Gnetum.*

Class Angiospermae: Flowering plants; seeds enclosed in an ovary which ripens into the fruit.

Subclass Monocotyledonae: Embryo with one cotyledon; fibrovascular tissues scattered through the stem tissues; flower parts in 3's and 6's; leaves parallel-veined: grasses, sedges, lilies, irises, orchids, palms (including about 9 orders).

Subclass Dicotyledonae: Embryo with two cotyledons; fibrovascular tissues in a zone around a central pith tissue in the stem; flower parts in 4's or 5's; leaves with netted veins: buttercups; roses, apples, elms (including about 35 orders).

KINGDOM ANIMALIA

Multicellular animals having tissues and, in many, organs and organ systems; pass through embryonic or larval stages in development; heterotrophic.

PHYLUM PORIFERA

Body in two cell layers, penetrated by numerous pores; "skeleton" formed by silicious or calcareous spicules or horny spongin; marine and fresh-water animals: sponges.

Class Calcispongiae: Simple sponges of shallow waters; calcareous spicules forming "skeleton": ascon and sycon sponges (*Grantia*).

Class Hylospongiae: Deep-water sponges; "skeleton" composed of silicious spicules in open framework: Venus's flower basket.

Class Demospongiae: Large sponges; often brilliantly colored; "skeleton" of spongin or a combination of spongin and silicious material; fresh-water and marine: bath sponge, finger sponge; crumb-of-bread sponge.

PHYLUM COELENTERATA

Usually free-swimming animals with a baglike body of two cell layers with a noncellular substance between them; gastrovascular cavity with one opening leading to the outside; many with tentacles and all with stinging capsules; solitary or colonial forms; marine and fresh-water: jellyfish.

Class Hydrozoa: Solitary or colonial; fresh-water and marine; reproduction by asexual buds and gametes; alternation of generations in many forms: *Hydra, Obelia, Gonionemus, Physalia.*

Class Scyphozoa: Exclusively marine; most have mesenteries; polyp stage usually absent: *Aurelia, Cyanea.*

Class Anthozoa: Marine forms; solitary or colonial; without alternation of generations; body cavity with mesenteries; numerous tentacles: sea anemones, corals, sea fans.

PHYLUM CTENOPHORA

Marine animals resembling jellyfish; hermaphroditic; definite digestive system with anal pore; biradially symmetrical: comb jellies.

PHYLUM PLATYHELMINTHES

Body flat and ribbonlike, without true segments; no body cavity, skeletal, circulatory, or respiratory systems; head provided with sense organs; nervous system composed of two longitudinal nerve cords: flatworms.

Class Turbellaria: Mostly free-living aquatic or terrestrial forms; many with cilia on the epidermis: *Planaria.*

Class Trematoda: Parasitic forms with mouth at anterior end; intestine present; no cilia on adults: human liver fluke, sheep liver fluke.

Class Cestoda: Parasitic forms; body a series of proglottids; intestine lacking; hooked scolex adapted for attachment to intestine of host: tapeworms.

PHYLUM NEMERTEA

Body elongated and flattened; long proboscis extending through mouth opening at anterior end; circulatory system present; bilaterally symmetrical; mostly marine: proboscis worms.

PHYLUM NEMATODA

Body slender and elongated; unsegmented; body wall in three layers; body cavity present; bilaterally symmetrical; free-living and parasitic forms: roundworms (*Ascaris*, *Trichinella*, pinworm, hookworm, vinegar eel).

PHYLUM NEMATOMORPHA

Body slender and elongated, resembling a hair; larvae parasitic in insects, adults free-living in fresh water; mouth often lacking in adults: horsehair worms ("horsehair snakes").

PHYLUM ACANTHOCEPHALA

Body elongated; digestive tract lacking; anterior proboscis armed with many recurved hooks; parasitic in vertebrates: spiny-headed worms.

PHYLUM TROCHELMINTHES (ROTIFERA)

"Wheel animals" with rows of cilia around the mouth which beat with a motion suggesting the rotation of a wheel; chitinlike jaws and a well-developed digestive system; body usually cylindrical, ending in a forked grasping foot: rotifers.

PHYLUM BRYOZOA

Microscopic organisms forming branching colonies; row of ciliated tentacles at anterior end; usually marine: bryozoans (sea mosses).

PHYLUM BRACHIOPODA

Body enclosed in dorsal and ventral shells resembling those of a clam; two spirally coiled arms within shell bearing a row of ciliated tentacles; simple circulatory system; marine animals; mostly fossil forms: brachiopods, lampshells.

PHYLUM PHORONIDEA

Wormlike animals; sedentary and tube-dwelling; spirally coiled arm with ciliated tentacles at anterior end; marine: *Phoronis*.

PHYLUM CHAETOGNATHA

Free-swimming, transparent, slender animals resembling arrows; mouth lined with curved bristles; body divided into head, trunk, and tail with finlike projections; marine: arrow worms.

PHYLUM MOLLUSCA

Soft-bodied animals without segments or jointed appendages; most forms secrete a valve, or calcareous shell, from a mantle; muscular foot usually present; terrestrial, fresh-water, and marine animals: mollusks.

Class Amphineura: Elongated body and reduced head, without tentacles; many forms with a shell composed of eight plates: chiton.
Class Pelecypoda: Axe-footed with bivalve shell; gills in mantle cavity; head, eyes, and tentacles lacking: clam, oyster, scallop.
Class Gastropoda: Flat-footed, with or without coiled shell; head, distinct eyes, and tentacles present: snail, slug, whelk.
Class Scaphopoda: Body elongated and enclosed in a tubular shell, open at both ends; gills lacking; marine animals: tooth shells.
Class Cephalopoda: Head large; foot modified into grasping tentacles; marine animals: squid, octopus, chambered nautilis, cuttlefish.

PHYLUM ANNELIDA

Segmented worms with the body cavity separated from the digestive tube; brain dorsal and nerve cord ventral; body wall containing circular and longitudinal muscles: segmented worms.

Class Polychaeta: Fleshy outgrowths, or parapodia extending from segments; marine animals: sandworm (*Nereis*).
Class Archiannelida: Similar to Polychaeta but without parapodia and with two rows of cilia: *Polygordius.*
Class Oligochaeta: Head not well developed; setae on body wall; terrestrial and fresh-water forms: earthworm, *Tubifex, Chaetogaster.*
Class Hirudinea: Body flattened from top to bottom; no setae on body; suckers at both ends; mostly fresh-water forms, but may occur as terrestrial or marine organisms: leeches.

PHYLUM ARTHROPODA

Animals with segmented bodies, the segments bearing jointed appendages; chitinous exoskeleton; aerial, terrestrial, and aquatic forms: arthropods.

Class Crustacea: Head and thorax joined in a cephalothorax; two pairs of antennae; mostly aquatic; gills for respiration; many with calcareous deposits in exoskeleton: crayfish, lobster, crab, shrimp, water flea, sowbug, barnacle.
Class Chilopoda: Body flattened and consisting of 15 to 170 or more segments; one pair of legs attached to each segment; maxillipeds developed into poison claws: centipedes.
Class Diplopoda: Body more or less cylindrical and composed of 25 to 100 or more segments; most segments bearing two pairs of legs: millepedes.
Class Arachnida: Head and thorax usually fused into a cephalothorax; antennae lacking; four pairs of legs; lung books and tracheae for respiration: spiders, scorpions, ticks, mites.

Class Insecta: Head, thorax, and abdomen separate; three pairs of legs; one pair of antennae; usually two pairs of wings; tracheae for respiration: insects.

Order Thysanura: Wingless; chewing mouthparts; no metamorphosis; primitive insects: silverfish.

Order Orthoptera: Two pairs of wings, the outer pair straight and leathery; chewing mouthparts; incomplete metamorphosis: grasshoppers, cockroaches, walking stick, mantis, crickets.

Order Isoptera: Some forms wingless, others with two pairs of long, narrow wings lying flat on back; chewing mouthparts; incomplete metamorphosis; social insects: termites.

Order Neuroptera: Four membranous wings of equal size, netted with many veins; chewing mouthparts; complete metamorphosis; larvae of some forms aquatic: dobson fly (hellgrammite), aphis lion.

Order Ephemerida: Two pairs of membranous wings, the front pair larger than the hind pair; mouthparts nonfunctioning in adults; metamorphosis incomplete; adults short-lived: Mayfly.

Order Lepidoptera: Four wings covered with colored scales; mouthparts modified into a coiled, sucking proboscis; complete metamorphosis: butterflies, moths, skippers.

Order Hymenoptera: Wingless or with two pairs of membranous wings, the fore wings larger; fore wings and hind wings hooked together; chewing and sucking mouthparts; complete metamorphosis; many members living in social colonies: bees, ants, wasps, hornets, ichneumon fly.

Order Odonata: Two pairs of strong, membranous wings, the hind pair as large or larger than the fore pair; chewing mouthparts; incomplete metamorphosis, compound eyes very large; larvae aquatic: dragonflies, damsel flies.

Order Mallophaga: Wings absent; chewing mouthparts; incomplete metamorphosis: chicken lice.

Order Anoplura: Wingless; piercing and sucking mouthparts; no metamorphosis; external parasites on mammals: human body louse.

Order Coleoptera: Four wings, the front pair hard and shell-like, the second pair folded and membranous; chewing mouthparts; complete metamorphosis: beetles, ladybugs, firefly, boll weevil.

Order Hemiptera: Wingless, or with fore wings leathery at the base and folded over the hind wings; piercing and sucking mouthparts; incomplete metamorphosis: true bugs, water bug, water strider, water boatman, back swimmer, bedbug, squash bug, stink bug.

Order Homoptera: Wingless, or with two pairs of wings held in a sloping position like the sides of a roof; piercing and sucking mouthparts; incomplete metamorphosis: cicada, aphids, leaf hopper, tree hopper, scale insects.

Order Diptera: Fore wings membranous, hind wings reduced to knobbed threads; mouthparts for piercing, rasping, and sucking; metamorphosis complete: housefly, bot fly, blowfly, midge, mosquitoes, crane fly, gall gnat.

Order Siphonaptera: Wingless; piercing and sucking mouthparts; complete metamorphosis; legs adapted for leaping; external parasites on mammals: fleas.

PHYLUM ECHINODERMATA

Radially symmetrical; spiny exoskeleton composed, in some cases, of calcareous plates; most forms with tube feet for locomotion; marine animals: echinoderms.

Class Crinoidea: Five branched rays and pinnules; tube feet without suckers; most forms with stalk for attachment; many fossil forms: sea lily.
Class Asteroidea: Body usually with five rays and double rows of tube feet in each ray; eyespot: starfish.
Class Ophiuroidea: Usually with five slender arms or rays: brittle stars.
Class Echinoidea: Body spherical, oval, or disk-shaped; rays lacking; tube feet with suckers: sea urchin, sand dollar.
Class Holothurioidea: Elongated, thickened body with tentacles around the mouth; no rays or spines: sea cucumber.

PHYLUM CHORDATA

Notochord present at some time, disappearing early in many forms; paired gill slits temporary or permanent; dorsal nerve cord.

SUBPHYLUM HEMICHORDATA: Wormlike chordates; body in three regions with a proboscis, collar, and trunk: acorn worm (tongue worm).
SUBPHYLUM TUNICATA (UROCHORDATA): Marine animals with saclike body in adult; free-swimming or attached: sea squirts and other tunicates.
SUBPHYLUM CEPHALOCHORDATA: Fishlike animals with a permanent notochord: lancelet (*Amphioxus*).
SUBPHYLUM VERTEBRATA: Chordates in which most of the notochord is replaced by a spinal column composed of vertebrae and encasing the dorsal nerve cord: vertebrates.
Class Cyclostomata (Agnatha): Fresh-water or marine eel-like forms without true jaws, scales, or fins; cartilaginous skeleton: lamprey, hagfish.
Class Chondrichthyes (Elasmobranchii): Fishlike forms with true jaws and fins; gills present but not free and opening through gill slits; no air bladder; cartilaginous skeleton: sharks, rays, skates.
Class Osteichthyes (Pisces): Fresh-water and marine fishes with gills free and attached to gill arches; one gill opening on each side of body; true jaws and fins; bony skeleton: bony fishes.

Subclass Ganoidei: Mostly extinct forms with armored body; heterocercal tail; air bladder with duct: sturgeon, garpike, amia, fossil armored fish.
Subclass Teleostomi: Tail rarely heterocercal; air bladder present or absent, with or without duct: perch, bass, trout, salmon, eel, catfish, shiner, flounder, cod, haddock.
Subclass Dipnoi: Air bladder connected with throat and used as a rudimentary lung: lungfish.

Class Amphibia: Fresh-water or terrestrial forms; gills present at some stage; skin slimy and lacking protective outgrowths; limbs without claws; numerous eggs, usually laid in water; metamorphosis: amphibians.

Order Apoda: Wormlike amphibians with tail short or lacking; without limbs or limb girdles; small scales embedded in the skin in some forms: caecilians.
Order Caudata: Body elongated and with a tail throughout life; scales lacking; most forms with two pairs of limbs: salamanders, newts, sirens.
Order Salientia: Body short and tailless in adult stage; two pairs of limbs, the hind limbs adapted for leaping; gills in larval stage, lungs in adult stage: frogs, toads, tree frogs.

Class Reptilia: Terrestrial or semiaquatic vertebrates; breathe by lungs at all stages; body scale-covered; feet, if present, provided with claws; eggs provided with a leathery, protective shell; fertilization internal; oviparous or ovoviviparous reptiles.

Order Testudinata (Chelonia): Body enclosed between two bony shields or shells, usually covered with large scales; toothless: turtles, terrapins, tortoises.
Order Rhynchocephalia: Skeletal characteristics of the oldest fossil reptiles; lizardlike in form; parietal eye in roof of cranium: tuatara (*Sphenodon*).
Order Squamata: Body elongated; with or without limbs (vestigial in snakes); body covered with scales which are molted with outer skin at regular intervals: snakes, lizards.
Order Crocodilia: Large, heavy-scaled body with strong, muscular tail; heart approaching four-chambered structure: alligators, crocodiles, caymans, gavials.

Class Aves: Body covered with feathers; forelimbs modified into wings; four chambered heart and double circulation; bones containing air cavities; lung breathing throughout life: birds.

Order Gaviiformes: Loons: common loon.
Order Columbiformes: Grebes: pied-billed grebe.
Order Pelecaniformes: Tropical birds: white pelican, brown pelican, cormorant.
Order Ciconiiformes: Long-legged wading birds: heron, bittern, ibis, spoonbill, flamingo.
Order Anseriformes: Short-legged gooselike birds: duck, goose, swan.
Order Falconiformes: Large birds of prey: hawk, falcon, eagle, kite, vulture, buzzard, condor.
Order Galliformes: Fowl-like birds: pheasant, turkey, quail, partridge, grouse, ptarmigan.
Order Gruiformes: Cranelike birds: crane, coot, gallinule, rail, limpkin.

Order Charadriiformes: Shore birds: snipe, sandpiper, plover, gull, tern, auk, puffin.
Order Columbiformes: Pigeons and doves: mourning dove, white-winged dove.
Order Psittaciformes: Parrots and parrotlike birds: parrots, parakeet, macaws.
Order Cuculiformes: Cuckoos: cuckoo, roadrunner.
Order Strigiformes: Nocturnal birds of prey: owls.
Order Caprimulgiformes: Goatsuckers: whippoorwill, chuck-will's widow, nighthawk.
Order Apodiformes: Swifts: chimney swift, hummingbird.
Order Coraciiformes: Fishing birds: kingfisher.
Order Piciformes: Woodpeckers: woodpecker, sapsucker, flicker.
Order Passeriformes: Perching birds: robin, bluebirds, sparrow, warbler, thrush.

Class Mammalia: Body more or less covered with hair; warm-blooded with four-chambered heart; mammary glands; diaphragm; central nervous system highly developed; viviparous except in one order.

Order Monotremata: Egg-laying mammals: duckbilled platypus, spiny anteater.
Order Marsupialia: Pouched mammels: opossum, kangaroo, Koala bear.
Order Insectivora: Insect-eating mammals: mole, shrew.
Order Chiroptera: Flying, or hand-winged mammals: bat, vampire.
Order Edentata: Toothless mammals: armadillo, sloth, great anteater.
Order Rodentia: Gnawing mammals: squirrel, woodchuck, prairie dog, chipmunk, mouse, rat, muskrat.
Order Lagomorpha: Rodentlike mammals: rabbits, hare, pika.
Order Cetacea: Marine mammals: whale, porpoise, dolphin.
Order Sirenia: Aquatic mammals: sea cow.
Order Proboscidea: Trunk-nosed mammals: elephant, fossil mammoth, fossil mastodon.
Order Carnivora: Flesh-eating mammals: bear, raccoon, ring-tailed cat, weasel, mink, otter, skunk, lion, tiger, cat, dog, fox, wolf.
Order Ungulata: Hoofed mammals: odd-toed (*Order Perissodactyla* in some classifications) — horse, tapir, rhinoceros; even-toed (*Order Artiodactyla* in some classifications) — bison, cow, goat, sheep, deer, antelope, camel, llama, pig, hippopotamus.
Order Primates: Erect mammals: monkey, lemur, marmoset, gibbon, orangutan, gorilla, chimpanzee, man.

A TRADITIONAL CLASSIFICATION OF ORGANISMS

KINGDOM PLANTAE

PHYLUM THALLOPHYTA

SUBPHYLUM ALGAE

Class Cyanophyceae: blue-green algae
Class Chlorophyceae: green algae
Class Chrysophyceae: yellow-green algae, golden-brown algae, diatoms
Class Phaeophyceae: brown algae
Class Rhodophyceae: red algae

SUBPHYLUM FUNGI

Class Schizomycetes: bacteria, rickettsiae, actinomycetes, spirochetes
Class Myxomycetes: slime fungi
Class Phycomycetes: algalike fungi
Class Ascomycetes: sac fungi
Class Basidiomycetes: basidium fungi
Class Deuteromycetes: imperfect fungi

PHYLUM BRYOPHYTA

Class Hepaticae: liverworts, hornworts
Class Musci: mosses

PHYLUM PTERIDOPHYTA

Class Filicineae: ferns
Class Equisetineae: horsetails
Class Lycopodiaceae: club mosses

PHYLUM SPERMATOPHYTA

Class Gymnospermae: gymnosperms

Order Cycadales: cycads or sago palms
Order Ginkgoales: Ginkgo
Order Coniferales: pine, spruce, fir, cedar, larch
Order Gnetales: Ephedra, Welwitschia, Gnetum

Class Angiospermae: flowering plants
Subclass Monocotyledonae
Subclass Dicotyledonae

KINGDOM ANIMALIA

PHYLUM PROTOZOA

Class Sarcodina: amoeboid organisms
Class Mastigophora: flagellates
Class Sporozoa: sporozoans
Class Ciliata: ciliates

(The additional phyla in the Traditional Classification are the same as those listed in the Modern Classification.)

GLOSSARY

abdomen, the body region posterior to the thorax.

abscission layer, the two rows of cells near the base of a leaf peticle that are involved in the natural falling of the leaf.

absorption, the process by which water and dissolved substances pass into cells.

acromegaly, abnormal growth, especially of the bones of the face and extremities, associated with malfunctioning of the anterior lobe of the pituitary gland.

ACTH, a hormone secretion of the anterior lobe of the pituitary gland which stimulates the cortex of the adrenal glands.

active transport, the passage of a substance through a cell membrane by means of energy.

adaptation, an adjustment to conditions in an environment.

adaptive radiation, a branching out of a population through variation and adaptation to occupy many environments.

addiction, the body's need for a drug which has been developed by the use of the drug.

adductor muscles, those in bivalves that control the opening and closing of the valves.

adenoid, a mass of lymph tissue that grows from the back wall of the nasopharynx, behind the internal nares.

ADP (adenosine diphosphate), a low energy compound found in cells which functions in energy storage and transfer.

adrenal gland, a ductless gland located above the kidney, often referred to as the "gland of emergency."

adventitious root, one which develops from the node of a stem or from a leaf.

aeciospore, a spore produced in an aecium cup on a leaf of common barberry in the life cycle of wheat rust.

aerial roots and stems, those which do not enter the ground.

aerobic, requiring free atmospheric oxygen for normal activity.

agglutinin, an immune substance in the blood which causes specific substances, including bacteria, to clump.

agglutinogen, a protein substance on a corpuscle surface which is responsible for blood types.

air bladder, a thin-walled, elliptical sac found in fish which allows the animal to maintain a level in the water.

air sacs, in insects, the enlarged spaces in which the tracheae terminate; in birds, cavities extending from the lungs; in man, thin-walled divisions of the lungs.

albumen, a protein substance that surrounds the yolk of a bird's egg.

alimentary canal, those organs composing the food tube in animals and man.

allantois, an extraembryonic membrane. In birds and reptiles it serves as an embryonic lung.

allele, one of a pair of genes for contrasting traits.

allergy, an abnormal reaction in some people to certain foods, drugs, and pollens.

alternation of generations, a type of life cycle in which the asexual reproductive stage alternates with the sexual reproductive stage.

alveoli, microscopic protrusions in the lungs in which the exchange of gases takes place.

amebocytes, amebalike cells in sponges which function in circulation and excretion.

amino acids, substances from which organisms build protein; the end-products of protein digestion.

ammonification, the release of ammonia from decaying protein by means of bacterial action.

amnion, the innermost fetal membrane, forming the sac that encloses the fetus and forms a sheath for the umbilical cord.

amniote egg, an egg having an amnion, a membrane that can be seen beneath the shell of a bird's egg.

amylase, an enzyme of the pancreatic fluid which changes starch to maltose.

anabolism, the constructive phase of metabolism.

anaerobic, deriving oxygen for life activity from chemical changes and, in some organisms, being unable to live actively in free oxygen.

anal pore, an opening in the pellicle of the paramecium by which wastes leave the animal.

analogous organs, those which are similar in function.

anaphase, a stage of mitosis during which chromosomes migrate from the equator to opposite poles.

anatomy, the study of the structure of living things.

annual, a plant which lives for only one season.

annual ring, a circle in the stem of a plant marking a season's growth of wood.

annulus, the ring on the stipe of a mushroom marking the point where the rim of the cap and stipe were joined.

antenna, a large "feeler" in insects and certain other animals.

antennule, a small "feeler" in the crayfish and certain other animals.

anterior, head, or front, end.

anther, that part of the stamen which bears pollen grains.

antheridium, a sperm-producing structure.

anthocyanin, a red, blue, or purple pigment dissolved in cell sap.

anthropology, the study of man and the societies in which he groups himself.

antibiotic, a germ-killing substance produced by a bacterium, mold, or other fungus plant.

antibody, an immune substance in the blood and body fluids.

antigen, a substance, usually a protein, which when introduced into the body stimulates the formation of antibodies.

antipodals, three nuclei found in the embryo sac at the end farthest from the micropyle.

antitoxin, a substance in the blood which counteracts a specific toxin.

antivenin, a serum used against snakebite.

anus, the opening at the posterior end of the intestine.

aorta, the great artery leading from the heart to the body (arising from the left ventricle in the bird and mammal).

aortic arch, an arching curve in the aorta, near the heart.

apical cell, the terminal, or tip, cell of a growing plant.

apical dominance, the influence of the terminal bud by its production of auxin which inhibits the growth of lateral buds.

appendage, an outgrowth of the body of an animal, such as a leg, fin, or antenna.

applied science, practical use of knowledge gained from pure science.

aquatic, living in water.

aqueous humor, the watery fluid filling the cavity between the cornea and lens of the eye.

arachnoid mater, the middle of the three membranes of the brain and spinal cord.

archegonia, an egg-producing structure.

arteriole, a tiny artery which eventually branches to become capillaries.

artery, a large, muscular vessel that carries blood away from the heart.

artificial pollination, controlled pollination to produce a hybrid plant from selected parents.

artificial respiration, a method of artificially forcing the lungs to inspire and expire rhythmically.

ascus, in Ascomycetes, the saclike structure which contains the spores.

asexual reproduction, reproduction without eggs and sperm.

association fibers, nerve processes connecting different parts of the cerebral cortex.

asters, the fibrils that form and radiate from the centriolelike rays from a star during cell division.

asymmetrical, having no definite shape.

atom, the smallest unit into which an element can be broken without losing its identity.

atomic mass, the sum of the protons and neutrons in the atom of an element.

atomic number, the number of protons in the nucleus of an atom. No two elements have atoms with the same number of protons.

ATP (**adenosine triphosphate**), a high-energy compound found in cells which functions in energy storage and transfer.

atrioventricular node, the structure in the heart which relays the beat to the muscles of the lower heart chamber.

atrioventricular valves, the heart valves located between the auricles and ventricles.

atrium, a thin-walled upper chamber of the heart.

auditory nerve, the nerve leading from the inner ear to the brain.

autonomic nervous system, a division of the nervous system which regulates the vital internal organs in an involuntary manner.

autosome, any paired chromosome other than the sex chromosomes.

autotrophs, organisms capable of organizing organic molecules from inorganic molecules.

axil, the angle between a leaf stalk and a stem.

axillary bud, a lateral bud produced in a leaf axil.

axon, a nerve process which carries an impulse away from the nerve body.

bacillus, a rod-shaped bacterium.

bacteria, a group of microscopic, one-celled protists.

bacteriology, the study of bacteria.

bacteriolysin, a blood antibody which causes a specific kind of bacteria to dissolve.

bacteriophage, one of several kinds of viruses that can destroy bacteria.

barb, a tiny ray in the vane of a feather.

barbule, one of the divisions of the barb of a feather.

bark, the outer region of a woody stem, composed of several kinds of tissue.

barrier, anything that prevents the spread of organisms to a new environment.

basal disk, the structure that secretes a slimy material by which certain coelenterates are attached to the substrate.

basal metabolism, the activities required to maintain the body and to supply the energy necessary to support the basic life processes.

basidiospore, a reproductive structure found in the basidiomycetes, or club fungi.

basidium, a club-shaped structure found in the club fungi that bears spores.

bast fiber, a tough, thick-walled plant fiber that serves as a supporting structure in the phloem region.

belly, the body of a striated muscle.

beta particles, high-speed electrons emitted by radioactive materials.

biennial, a plant that lives two seasons.

bilateral symmetry, the type exhibited by organism that may be divided into two equal parts by only one plane.

bile, a brownish-green emulsifying fluid secreted by the liver and stored in the gall bladder.

binary fission, the division of cells into two approximately equal parts.

binomial nomenclature, the system of giving an organism a two-part name.

biogenesis, the biological principle that life arises from life.

biogeography, the study of the distribution of plants and animals throughout the various regions of the earth.

biology, the science of life.

biome, a large geographical region identified mainly by its climax vegetation.

biosphere, the area in which life is possible on our planet.

biosynthesis, the organization of organic molecules by living organisms.

biotic community, all the living organisms in an ecosystem.

biotic factors, the living surroundings of an organism.

bivalve, a mollusk possessing two valves, or shells.

blastocoel, the space between the ectoderm and endoderm in the early stages of embryological development.

blastula, an early stage in the development of an embryo, in which cells have divided to produce a hollow sphere.

blood, the fluid tissue of the body.

bony layer, the hard region of a bone between the periosteum and the marrow.

botulism, a severe type of food poisoning caused by a bacillus.

Bowman's capsule, the tuft-shaped structure forming one end of the tubules in the nephron of the kidney.

brain stem, an enlargement at the base of the brain where it connects with the spinal cord.

branchial arteries, those that lead to and from the gills of the fish.

breathing, the mechanical process of getting air into and out of the body.

bronchial tube, a subdivision of a bronchus within a lung.

bronchiole, one of numerous subdivisions of the bronchial tubes within a lung.

bronchus, a division of the lower end of the trachea, leading to a lung.

bud, an undeveloped shoot of a plant, often covered by scales.

budding, the uniting of a bud with a stock; a form of asexual reproduction in yeasts and hydra.

bud-mutant, the offspring of a plant in which a mutation has occurred.

bud scales, small leaflike structures which completely enclose the tender growing point to protect the delicate tissues inside from drying and mechanical damage.

bud-scale scar, a mark at intervals along a twig which shows where the bud scales of a terminal bud were fastened during a previous season.

bulb, a large underground bud protected by scales.

bulbus arteriosus, a muscular bulblike structure attached to the ventricle in the fish heart.

Calorie (large), the amount of heat required to raise the temperature of 1,000 grams of water one degree centigrade.

cambium, the tissue in roots and stems responsible for growth in diameter.

capillary, a tiny blood vessel through which exchange of gases, foods, and wastes takes place between the blood and tissue fluid.

catabolism, the destructive phase of metabolism.

catalyst, a substance that accelerates a chemical reaction without itself being permanently altered chemically.

cell wall, the outer, nonliving, cellulose wall secreted around plant cells.

cellulose, a carbohydrate substance present in the walls of plant cells.

cementum, the covering of the root of a tooth.

central cylinder, the central core of a root, where conduction occurs.

central nervous system, the brain and spinal cord.

central neurons, those in the brain and spinal cord that connect motor nerves to sensory nerves.

centriole, a cytoplasmic body lying just outside the nucleus in animal cells. Its division is perhaps the earliest event in cell division.

centromere, a single granule that, during cell division, attaches after replication and just before separation.

cephalothorax, a body region in crustaceans and certain other animals consisting of the head and thorax.

cerebellum, the brain region between the cerebrum and medulla, concerned with equilibrium and muscular coordination.

cerebrospinal fluid, a clear fluid in the brain ventricles and surrounding the spinal cord.

cerebrum, the largest region of the human brain, considered to be the seat of emotions, intelligence, and other nervous activities.

cervix, the neck of the uterus.

chemical change, matter changing from one substance to another as a result of a chemical reaction.

chemosynthesis, the organization of carbohydrates by organisms by means of energy from inorganic chemical reactions instead of energy from light.

chitin, a material present in the exoskeleton of insects and other arthropods.

chlorophyll, green pigments essential to food manufacture in plants.

chloroplast, a plastid containing chlorophyll.

chondriosome, a structure in the cell whose exact function is unknown.

chorion, a membrane that forms early during development and attaches to the uterine wall.

chorionic villi, small, fingerlike projections attaching the chorion to the uterine wall.

choroid layer, the second and innermost layer of the eyeball.

chromatid, during cell division, each part of a double chromosome after duplication.

chromatophores, structures containing pigments in the skin of fish and other animals.

chromoplasts, plastids containing pigments other than chlorophyll.

chromosome, a rod-shaped gene-bearing body in the cell nucleus. It is composed of DNA joined to protein molecules.

chrysalis, a hard case containing the pupal stage of a butterfly.

chyme, partly digested, acidic food as it leaves the stomach.

cilia, tiny hairlike projections of cytoplasm.

ciliary muscles, those which control the shape of the lens.

cleavage, the division of the cytoplasm into two approximately equal parts during cell division.

cleavage furrow, an indentation that appears during the telophase of dividing animal cells.

climax plant, a species that assumes final prominence in a region.

clitellum, a swelling on the earthworm involved in reproduction.

cloaca, a chamber below the large intestine in certain vertebrates into which the alimentary canal, ureters, bladder, and reproductive organs empty.

coccus, a sphere-shaped bacterium.

cochlea, the hearing apparatus of the inner ear.

cocoon, a silken case containing the pupal stage of a moth.

coeolom, the space between the mesodermal layers that forms the body cavity of the animal.

cohesion, the clinging together of molecules, as in a column of liquid.

collar cells, flagellated cells in sponges which set up water currents.

colloid, a gelatinous substance such as protoplasm or egg albumen in which one or more solids are dispersed through a liquid.

colon, the large intestine.

colonial, living in a group, with each individual living independently but in close association with the others.

comb, the structure in the beehive composed of six-sided cells made of wax.

commensalism, one organism living in or on another, with only one of the two benefiting.

companion cells, long, narrow, nucleated cells bordering sieve tubes in phloem tissue.

complete metamorphosis, four stages of development of certain insects — egg, larva, pupa, and adult.

compost, a mixture of leaves and soil used for fertilizing and conditioning land.

compound, two or more elements combined chemically.

compound eye, an eye composed of numerous lenses and containing separate nerve endings, as in insects and crustaceans.

compound leaf, a leaf in which the blade is divided into leaflets.

conditioned reaction, a behavior pattern in which a particular response continually follows a specific stimulus.

cone, a reproductive part of a conifer; also a color-sensitive nerve ending in the retina of the eye.

conifer, a cone-bearing gymnosperm.

conjugation, a primitive form of sexual reproduction in *Spirogyra* and certain other algae and fungi in which the content of two cells unite; also an exchange of nuclear substance in the paramecium, resulting in rejuvenation of the cells.

connective tissue, a type of tissue that lies between groups of nerve, gland, and muscle cells and beneath epithelial cells; also includes bone, cartilage, blood, and lymph.

conservation, the preservation and wise use of natural resources.

consumers, the heterotrophs in an environment.

contact infection, a disease spread through direct contact with an infected person.

contour farming, the practice of following the contour around a slope in plowing.

contour feathers, those that cover a bird's body and give it a smooth outline.

contractile vacuole, a large cavity in protozoans associated with the discharge of water from the cell and the regulating of osmotic pressure.

contraction (muscle), the shortening of a striated muscle.

conus arteriosus, a large vessel lying against the front side of the frog's heart and leading from the ventricle.

convergent evolution, the type in which organisms of entirely different origin evolve in a manner that results in certain similarities.

convolution, one of many irregular, rounded ridges on the surface of the brain.

cork, a tissue formed by the cork cambium which replaces the epidermis in woody stems and roots.

cork cambium, a layer of cells in the outer bark which produces new cork.

corm, a shortened underground stem in which the leaves are reduced to thin scales.

cornea, a transparent bulge of the sclerotic layer of the eye in front of the iris, through which light rays pass.

corolla, the petals of a flower, collectively.

coronary, pertaining to the heart.

corpus luteum, refers to the follicle after the ovum is discharged.

corridor, a pathway that allows the spread of a population to new areas.

cortex, in roots and stems, a storage tissue; in organs such as the kidney and brain, the outer region.

cortin, a hormone complex secreted by the cortex of the adrenal glands.

cotyledon, a seed leaf present in the embryo plant that serves as a food reservoir.

countershading, a form of protective coloration in which darker colors on the upper side of the animal fade into lighter colors on the lower side.

covalent bond, a force holding atoms together that results from the sharing of pairs of electrons.

cover crop, a crop such as wheat and oats in which the plants grow close together and bind the soil with their closely mingled roots.

coverts, the small feathers that cover the lower portions of the quill feathers in birds.

Cowper's gland, located near the upper end of the male urethra. It secretes a fluid which is added to the sperm.

coxa, a joint of the leg of the grasshopper which, with the trochanter, acts like a ball and socket.

cranial cavity, the cavity in the skull containing the brain.

cranial nerves, the twelve pairs of nerves connected to the human brain.

cretinism, a stunted condition resulting from lack of thyroid secretion.

crop, an organ of the alimentary canal of the earthworm, bird, and certain other animals which serves for food storage.

crop rotation, alternation in the planting of crops that use nitrates with those that replace nitrates.

cross-pollination, the transfer of pollen from the anther of one plant to the stigma of another.

crossing-over, the exchange of segments of two chromosomes, and the genes in the segments, when the two chromosomes lie side by side during reduction division.

crown, the exposed portion of a tooth above the gum line.

culture medium, a nutrient mixture used for growing bacteria, molds, and other fungi.

cuticle, a waxy, transparent layer covering the upper epidermis of certain leaves; the outer covering of an earthworm.

cyst, in lower animals and plants, a spore with a capsule covering constituting a resting stage.

cytoplasm, the protoplasm lying outside the nucleus of a cell.

dark reaction, the second stage of photosynthesis during which carbon is fixed in a series of chemical reactions, none of which require light.

daughter cell, a newly formed cell resulting from the division of a previously existing cell called a mother cell. The two daughter cells receive nuclear materials that are identical.

decay, the reduction of the substances of a plant or animal body to simple compounds by the action, usually, of bacteria.

deciduous, woody plants that shed their leaves seasonally.

decomposers, organisms that break the tissues and excretions of other organisms into simpler substances through the process of decay.

deficiency disease, a condition resulting from the lack of one or more vitamins.

degeneration, the loss of a system or structure by an animal.

dehiscent, a class of fruits that open and discharge seeds.

dehydration, loss of water from body tissues.

deliquescent, a type of branching in which the trunk divides into several main branches, resulting in a wide, spreading crown.

dendrite, a branching nerve process which carries an impulse toward the nerve cell body.

denitrification, the process carried on by denitrifying bacteria of breaking down ammonia, nitrites, and liberating free nitrogen.

dentine, a substance that is relatively softer than enamel, forming the bulk of the tooth.

deoxygenation, the process during which oxygen is removed from the blood or tissues.

depletion, mineral exhaustion of the soil through continued planting of agricultural crops without proper fertilizing.

dermis, the skin layer beneath the epidermis.

diabetes mellitus, a condition resulting from lack of insulin so that the body cannot store or oxidize sugar efficiently.

diaphragm, a muscular partition separating the thoracic cavity from the abdominal cavity.

diastase, an enzyme in green plants that changes starch to sugar.

diastolic blood pressure, arterial blood pressure maintained between heartbeats.

dicotyledon, a seed plant with two seed leaves, or cotyledons.

differentially permeable membrane, one which is permeable to different substances to different degrees.

diffuse root system, one composed of spreading roots of similar size.

diffusion, the spreading out of molecules in a given space.

diffusion pressure, the force resulting from differences in molecular concentration, temperature, and pressure.

digestion, the process during which foods are chemically simplified and made soluble so that they can be used by the cells.

dihybrid, an offspring having genes for two contrasting characters.

diploid number, the full set of chromosomes in a nucleus, with both members of each pair present.

diurnal, active during the day.

division of labor, specialization of cell functions resulting in interdependence.

division plate, a wall of cellulose which forms across the dividing plant cell forming a common boundary between daughter cells.

DNA (deoxyribonucleic acid), a super molecule consisting of alternating units of deoxyribose sugar, phosphates, and organic bases. DNA transmits hereditary information and controls cellular activities.

dominant, in genetics, refers to a trait that appears in a hybrid.

dormancy, a period of inactivity.

dorsal, pertaining to the upper surface of an animal.

double-cross, one in which four pure-line parents are mixed in two crosses.

down feathers, those that form the plumage of newly hatched birds.

drone, the male bee.

droplet infection, a disease spread through cough or sneeze droplets bearing microorganisms from the respiratory tract or mouth.

ductus arteriosus, a connection between the pulmonary artery and the aorta during fetal life. It closes at birth.

duodenum, the region of the small intestine immediately following the stomach; in man, about 10 inches long.

dura mater, the outer of the three membranes of the brain and spinal cord.

ecology, the study of the relationship of living things to their surroundings.

ecosystem, a unit of the biosphere in which living and nonliving things interact, and in which materials are used over and over again.

ectoderm, the outer layer of cells of a simple animal body; in vertebrates, the layer of cells from which the skin and nervous system develop.

ectoplasm, the outer layer of thin, clear cytoplasm, as in the ameba.

elongation region, the area behind the embryonic region of a root or stem in which cells grow in length.

embryo, a developing organism.

embryo sac, the tissue in a plant ovule that contains the egg, the antipodals, the polar nuclei, and the synergids.

embryonic region, the area near the tip of a root or stem in which cells are formed by division.

enamel, the hard covering of the crown of a tooth.

endocrine gland, a ductless gland which secretes hormones directly into the blood.

endoderm, the inner layer of cells of a simple animal body; in vertebrates, the layer of cells from which the lining of the digestive system, the liver, the lungs, etc. develop.

endodermis, a single layer of cells located at the inner edge of the cortex of a root.

endoplasm, the inner layer of cytoplasm, as in the ameba.

endoplasmic reticulum, a complex system of membranes which tend to lie parallel to one in the cytoplasm.

endosperm, the tissue in some seeds containing stored food.

enzyme, an organic catalyst.

epidermis, the outer tissue of a young root or stem, a leaf, and other plant parts; the outer layer of skin.

epithelial tissue, that composing the covering of various body organs.

erepsin, a digestive enzyme of the intestinal fluid which changes peptides to amino acids.

erosion, the loss of soil by the action of water or wind.

esophagus, the food tube, or gullet, which connects the mouth and the stomach.

estivation, a period of summer inactivity in certain animals.

estrogen, a female hormone secreted by the ovaries.

eugenics, the science of human heredity.

Eustachian tube, a tube connecting the pharynx with the middle ear.

evaporation, movement of water from the earth to the atmosphere.

evolution, the slow process of change by which organisms have acquired their distinguishing characteristics.

excretion, the process by which waste materials are removed from living cells or from the body.

excurrent, a form of branching in which a single stem extends through a plant as a shaft.

excurrent pore, in sponges, the osculum.

excurrent siphon, the structure in the clam through which water passes out of the body.

exoskeleton, the hard, outer covering or skeleton of certain animals, especially arthropods.

exotoxin, a soluble toxin excreted by certain bacteria and absorbed by the tissues of the host.

expiration, the discharge of air from the lungs.

extensor, a muscle which straightens a joint.

external respiration, the exchange of gases between the atmosphere and the blood.

extinct, no longer in existence.

extraembryonic membrane, a membrane which functions during development of a mammal, but does not become part of the embryo.

eyespot, the sensory structure in the euglena and planaria that is believed to perceive light and dark.

facultative anaerobes, organisms that grow best as aerobes but may grow, at least to some extent, as anaerobes.

Fallopian tube, oviduct in the mammal.

fang, a hollow tooth of a poisonous snake through which venom is ejected.

farm ponds, artificial bodies of water which farmers may make and stock with some species of fish.

fat bodies, structures in the frog that store fat.

fats, a class of foods which supplies energy to the body.

fatty acids, one of the end-products of fat digestion.

feces, solid intestinal waste material.

femur, the long bone of the upper leg.

fermentation, glucose oxidation that is anaerobic and in which lactic acid or alcohol is formed.

fertilization, the union of sperm and egg.

fetus, mammalian embryo after the main body features are apparent.

fibrin, a substance formed during blood clotting by the union of thrombin and fibrinogen.

fibrinogen, a blood protein present in the plasma, involved in clotting.

fibrous root, a small, slender secondary root that is generally very much branched.

fibrovascular bundle, a strand containing xylem and phloem tissues in higher plants.

filament, a stalk of a stamen, bearing the anther at its tip; in algae, a threadlike group of cells.

filoplume, the slender, hairlike feathers in birds, having a tuft at the end.

filterable virus, a virus that passes through the extremely small pores of unglazed porcelain filters used in separating bacteria from fluids.

fin, a membranous appendage of a fish and certain other aquatic animals.

fire line, a lane cut through a forest to prevent a possible fire from spreading.

fish ladder, channel around a dam through which fish can travel upstream.

flagellate, an organism bearing one or more whiplike appendages, or flagella.

flagellum, a whiplike projection of cytoplasm used in locomotion by certain simple organisms.

fleshy root, an enlarged root which serves as a reservoir of food for the plant.

flexor, a muscle which bends a joint.

flower, an organ of a flowering plant specialized for reproduction.

follicle, an indentation in the skin from which hair grows; a mass of ovarian cells which produces an ovum.

food, any substance absorbed into the body which yields material for energy, growth, and repair of tissue and regulation of the life processes, without harming the organism.

food-borne infection, any infection caused by contaminated food.

food chain, the transfer of the sun's energy as organisms feed on one another.

food infection, the introduction of infectious organisms into the body by means of food.

food poisoning, a condition resulting from the action of preformed toxins present in food.

food pyramid, a quantitative representation of a food chain with the food producers forming the base and the top carnivore at the apex.

forage fishes, species that have no sport value but are vital as a food for game fishes.

forebrain, that part of the brain composed of the cerebrum.

fovea, a small, sensitive spot on the retina of the eye where cones are specially abundant.

fraternal twins, those that are produced from two separately fertilized eggs.

frond, the leaf of a fern.

fruit, a ripened ovary, with or without associated parts.

FSH (follicle-stimulating hormone), a hormone produced by the anterior lobe of the pituitary.

fungus, a protist lacking chlorophyll and therefore deriving nourishment from an organic source.

gallbladder, a sac in which bile from the liver is stored and concentrated.

game birds, those that have sport value for hunters.

game fishes, those that have sport value.

gamete, a male or female reproductive cell, or germ cell.

gametophyte, the stage that produces gametes in an organism having alternation of generations.

gamma globulin, a blood protein sometimes used to give temporary immunity to polio.

ganglion, a mass of nerve cells lying outside of the central nervous system.

gastric caeca, structures in the digestive system of the grasshopper.

gastrocoel, the central cavity occurring in the early stages of embryonic development.

gastrovascular cavity, the central cavity of Coelenterata.

gastrula, a stage in embryonic development during which the primary germ layers are formed.

gemmule, a coated cell mass produced by the parent sponge and capable of growing into an adult sponge.

gene, that portion of a DNA molecule that is genetically active and produces a trait.

gene frequency, the extent to which a gene occurs in a population.

gene linkage, the assemblage of genes in a linear arrangement on a chromosome.

gene pool, all the genes present in a given population.

generative nucleus, the nucleus in a pollen grain that divides to form two sperm.

genetic code, the sequential arrangement of the bases in the DNA molecule which controls the traits of an organism.

genetics, the science of heredity.

genotype, the hereditary make-up of an organism.

genus, a group of closely related species.

geologist, a scientist who studies the earth.

geotropism, the response of plants to gravity.

germination, growth of the seed when favorable conditions occur.

gestation period, the period between fertilization and birth of a mammal.

gill, an organ modified for absorbing dissolved oxyen from water; in mushrooms, a platelike structure bearing the reproductive organs.

gill arch, a cartilaginous structure in fish to which the gill filaments are attached.

gill filament, one of many threadlike projections forming the gills in fish.

gill raker, fingerlike projections of the gill arches in fish.

gizzard, an organ in the digestive system of the earthworm and birds modified for grinding food.

glomerulus, the knob of capillaries in a Bowman's capsule.

glottis, the upper opening of the trachea in land vertebrates.

glucose, a simple sugar, or monosaccharide, which is a product of photosynthesis and which is also an end-product of digestion.

glycerin, one of the end-products of fat digestion.

glycogen, animal starch, formed in the liver and muscles.

goiter (simple), an enlarged condition of the thyroid gland, resulting from iodine deficiency.

Golgi bodies (**Golgi apparatus**), small groups of parallel membranes in the cytoplasm near the nucleus, especially prominent in secretory cells. Their function is not known.

gonadotropic hormone, a hormone of the anterior lobe of the pituitary gland which influences activity of the reproductive organs.

gonads, the male and female reproductive organs.

grafting, the union of the cambium layers of two woody stems, one the stock and the other the scion.

green gland, an excretory organ of crustaceans.

ground water, that which enters the soil following precipitation.

guard cell, one of the two epidermal cells surrounding a stoma.

gullet, the passageway to a food vacuole in paramecia; the food tube or esophagus.

gully erosion, an advanced stage of water erosion following rill erosion.

habitat, place where an organism lives.

half-life, time required for one-half of a given amount of radioactive substance to disintegrate.

haploid number, half the number of chromosomes that are ordinarily present in the nucleus; occurs during reduction division.

haustoria, short, branching hyphae that absorb nourishment in certain fungi.

Haversian canals, numerous channels penetrating the ebony layer of a bone.

heartwood, inner, inactive wood usually darker in color than sapwood.

hemoglobin, an iron-containing protein compound giving red corpuscles their color; combines easily with oxygen.

hemophilia, an inherited disease in which the blood does not clot properly.

hemotoxin, a poison that destroys red blood cells and breaks down the walls of small blood vessels.

hepatic portal vein, a vessel carrying blood to the liver before the blood returns to the heart.

herbaceous, an annual stem with little woody tissue.

herbivores, plant-eating animals.

heredity, the transmission of traits from parent to offspring.

hermaphroditic, having the organs of both sexes.

heterocysts, in *Nostoc*, empty cells with thick walls which enable the filaments to break into shorter pieces.

heterogametes, male and female gametes which are unlike in appearance and structure.

heterotrophs, organisms that are unable to synthesize organic molecules from inorganic molecules, i.e., nutritionally dependent.

heterozygous, refers to an organism in which the paired genes for a particular trait are different.

hexose, the saccharide, or sugar unit, of which all sugars are composed.

hibernate, to spend the winter months in an inactive condition.

hilum, the scar on a seed where it was attached to the ovary wall.

hindbrain, that part of the brain which is composed of the cerebellum, the pons, and the medulla.

holdfast, the special cell at the base of certain algae that anchors them to the substrate.

homeostasis, a steady state which an organism maintains by self-regulating adjustments.

homoiothermic ("warm-blooded"), refers to animals whose internal temperature remains relatively constant regardless of the environmental temperature.

homologous chromosomes, the corresponding chromosomes of a pair.

homologous organs, those similar in origin and structure but not necessarily in function.

homologue, a single chromosome of a homologous pair.

homozygous, refers to an organism in which the paired genes for a particular trait are identical.

hormone, the chemical secretion of a ductless gland producing a definite physiological effect.

horny layer, the outer layer of the epidermis; in bivalves, the outermost layer of the shell.

host, in a parasitic relationship, the organism from which the parasite derives its food supply.

humus, organic matter in the soil formed by the decomposition of plant and animal remains.

hybrid, an offspring from a cross between parents differing in one or more traits.

hybrid vigor, having desirable characteristics lacking in both parents.

hybridization, the crossing of two different varieties to produce a new one.

hydrolysis, the breakdown of fats into fatty acids and glycerol by combination with water.

hydrophytes, plants that grow in water or partially submerged in water in very wet surroundings.

hydrotropism, the response of roots to water.

hyperthyroidism, overactivity of the thyroid gland and its attendant symptoms.

hypha, a threadlike filament of the vegetative body of a fungus.

hypocotyl, that part of a plant embryo from whose lower end the root develops.

hypothesis, a scientific idea or working theory.

hypothyroidism, underactivity of the thyroid gland and its attendant symptoms.

identical twins, those which develop from the fertilization of one egg which later splits into two organisms.

ileum, the third and longest region of the small intestine.

immune therapy, the assistance and stimulation of the natural body defenses in preventing infectious disease.

immunity, the ability of the body to resist a disease by natural or artificial means.

improvement cutting, the removal of diseased or injured trees from a managed forest.

inbreeding, line breeding.

incisor, a tooth in the front of the jaw; highly developed for gnawing in rodents.

incomplete dominance, the equal appearance of two unlike characteristics in the offspring, resulting from a cross of these characteristics.

incomplete metamorphosis, the life stages of certain insects consisting of the egg, several nymph stages, and the adult.

incubation, the providing of ideal conditions for growth and development, as in the incubation of eggs or the growth of bacteria.

incurrent pore, one of many holes in the sponge through which water passes into the animal.

incurrent siphon, the structure in a clam through which water passes into the body.

indehiscent, a class of fruits which do not open to discharge seeds.

individual characteristics, traits that are inherited but that make an organism different from all others.

innate behavior, inborn behavior.

inoculation, voluntary addition of germs or viruses to a culture medium or to a living organism.

inorganic, refers to a compound not containing carbon, with the exception of CO_2.

insecticide, a chemical used to destroy insects.

insertion, the attachment of a muscle at its movable end.

inspiration, the intake of air into the lungs.

instinct, a natural urge, or drive, not depending on experience or intelligence.

insulin, a hormone secretion of the islet cells of the pancreas which regulates the oxidation of sugar in the tissues.

integument, one of the two layers of the walls of an ovule.

interdependence, the dependence of cells on other cells for complete functioning, or of organisms on the activities of other organisms.

internal respiration, the exchange of gases between the blood and body tissues.

internode, the space between two nodes.

interphase, the period of growth of a cell that occurs before and after mitosis.

intestine, the portion or portions of the alimentary canal extending beyond the stomach.

invertebrate, an animal lacking a backbone.

involuntary muscle, one which cannot be controlled at will.

ionic bonds, forces holding atoms together resulting from differences in electrical charges.

ions, charged atoms.

iris, the muscular, colored portion of the eye, behind the cornea and surrounding the pupil.

irrigation, of soil, diversion of water into an area during dry periods.

irritability, the ability to respond to a stimulus.

islets of Langerhans, the special cells in the pancreas that secrete insulin.

isogametes, male and female gametes that look alike.

isolation, the confinement of a population to a certain location because of barriers.

isotopes, different forms of an element resulting from varying numbers of neutrons.

jejunum, a section of the small intestine lying between the duodenum and the ileum.

joint, the point at which two separate bones are joined by ligaments.

kidney, a glandular organ which excretes urine.

Koch postules, the steps in Robert Koch's procedure in the investigation of anthrax.

labium, the lower portion or "lip" of an insect's mouth.

labrum, the two-lobed upper portion of an insect's mouth.

lactase, a digestive enzyme of the intestinal fluid which changes lactose to glucose.

lacteal, a lymph vessel which absorbs digested fat from the intestinal wall.

lactic acid, a product of anaerobic respiration.

larva, the stage that follows the egg in the development of certain animals.

larynx, the voice box; also called the "Adam's apple."

lateral bud, a bud that develops at a point other than at the end of a stem.

lateral line, a row of pitted scales along each side of the fish, functioning as a sense organ.

leaching, the loss of soluble soil minerals as a result of the movement of ground water.

leaf, the photosynthetic organ of the plant.

leaf scar, a mark on a twig left at the point of attachment of a leaf stalk of a previous growing season.

leaflet, a division of a compound leaf.

lens, the transparent disk by means of which light rays are directed to the retina of the eye.

lenticel, a small pore in the epidermis or bark of a young stem through which gases are exchanged.

lethal gene, one which bears a characteristic that is usually fatal to the organism.

leucocytes, phagocytic white blood cells.

leucoplast, a colorless plastid serving as a food reservoir in certain plant cells.

LH (**luteinizing hormone**), a substance produced by the pituitary gland which controls the development of the corpus luteum.

life span, the period of existence of an organism.

ligament, a tough strand of connective tissue which holds bones together at a joint.

light reaction, the first stage of photosynthesis in which light energy excites chlorophyll molecules and causes water molecules to be split.

limiting factor, any factor that is essential to organisms and for which there is competition.

line breeding, the process of allowing plants to self-pollinate over several generations, removing offspring with undesirable traits in each generation; inbreeding in plants and animals.

lipase, a digestive enzyme of the pancreatic fluid that changes fats to glycerin and fatty acids.

liver, the largest organ in the human body, associated with several vital activities including digestion and sugar metabolism.

locomotion, the spontaneous movement of an organism from one place to another.

lung, an organ for aerial breathing.

lung books, the respiratory organs of spiders.

lymph, the clear, liquid part of blood which enters the tissue spaces and lymph vessels.

lysogenic phage, a virus that invades a bacterial cell without causing immediate destruction. It is passed along to daughter bacteria and becomes destructive at a later time.

lysozyme, an enzyme which dissolves the cell walls of many bacteria.

lytic cycle, the disintegration of a cell as a result of invasion by a phage.

macronucleus, the large nucleus of the paramecium and certain other protozoans.

maggot, the larval stage of a fly.

Malpighian tubules, the structures in the digestive system of the grasshopper that collect wastes from the blood.

maltase, a digestive enzyme of the intestinal fluid which changes maltose to glucose.

mammary glands, those found in female mammals that secrete milk and give the class its name.

mandible, a strong cutting mouthpart of arthropods; a jaw, as in the beak of a bird or the bony structure of a mammal.

mantle, the tissue covering the safe parts of a mollusk.

marine, living in salt water.

marrow, the soft tissue in the central cavity of a larger bone.

mass selection, the picking of ideal plants or animals from a large number to serve as parents for further breeding.

matrix, a gelatinous secretion of cells of *Nostoc* and certain other blue-green algae.

maturation region, the area of a root or stem where embryonic cells mature into tissues.

maxilla, a mouthpart of an arthropod; the upper jaw of vertebrates.

maxilliped, a "jaw foot," or first thoracic appendage, of the crayfish and other arthropods.

medulla, in the kidney, the inner portion containing pyramids which in turn contain numerous tubules; in the adrenal gland, the inner portion, which secretes epinephrine.

medulla oblongata, the enlargement at the upper end of the spinal cord, at the base of the brain.

medusa, the bell-shaped, free-swimming form in the jellyfish.

megaspores, four cells formed from the megaspore mother cell, three of which disintegrate and one of which develops into the embryo sac.

megaspore mother cells, diploid cells in the plant ovary which divide twice, forming four haploid magaspores.

meiosis, the type of cell division in which there is reduction of chromosomes to the haploid number during oogenesis and spermatogenesis.

meninges, the three membranes covering the brain and spinal cord.

menstruation, the periodic breakdown and discharge of soft uterine tissues that occurs in the absence of fertilization.

meristematic tissue, small, actively dividing cells that produce growth in plants.

mesentery, a folded membrane which connects to the intestines and the dorsal body wall of vertebrates.

mesoderm, the middle layer of cells in an embryo.

mesoglea, a jellylike material between the two cell layers composing the body of a coelenterate.

mesophytes, plants which occupy neither extremely wet nor extremely dry surroundings.

mesothorax, the middle portion of the thorax of an insect, bearing the second pair of legs and usually a pair of wings.

messenger RNA, the type of RNA that is thought to receive a code for a specific protein from the DNA in the nucleus and to act as a template for protein synthesis on the ribosome.

metabolism, the sum of the chemical process of the body.

metamorphosis, a marked change in structure of an animal during its growth, as the change from larva to pupa and adult in insects.

metaphase, the stage of mitosis in which the chromosomes line up at the equator.

metathorax, the posterior portion of the thorax of an insect, bearing the third pair of legs and the second pair of wings.

micronucleus, a small nucleus found in the paramecium and certain other protozoans.

micropyle, the opening in the ovule wall through which the pollen tube enters.

microspore mother cells, diploid cells in the anther which divide twice, forming four haploid microspores.

microspores, four cells, formed from the microspore mother cell, which develop into pollen grains.

midbrain, that part of the brain which is composed of nerve fibers connecting the forebrain to the hindbrain.

middle lamella, a portion of the plant cell wall that forms a common boundary between two touching cells.

midrib, the large, central vein of a pinnately veined leaf.

migration, seasonal movement of animals from one place to another.

mimicry, a form of protective coloration in which an animal closely resembles another kind of animal or an object in its environment.

mitochondria, rod-shaped bodies in the cytoplasm known to be centers of cellular respiration.

mitosis, the division of chromosomes preceding the division of cytoplasm.

mixed nerve, one which consists of both sensory and motor nerve fibers.

mixture, two or more substances that intermingle without chemical combination.

molar, a large tooth for grinding, highly developed in herbivores.

molecule, the smallest portion of a substance that keeps the properties shown by that substance in large quantities.

molting, shedding of the outer layer of exoskeleton or arthropods, or of a scale layer of reptiles, or of plumage of birds.

monocotyledon, a flowering plant that develops a single seed leaf or cotyledon.

monoecious, bearing staminate and pistillate flowers on different parts of the same plant.

monohybrid, an offspring from a cross between parents differing in one trait.

mother cell, a cell that has undergone growth and is ready to divide.

motor end plate, the terminus of the axon of a motor nerve in a muscle.

motor nerve, one containing only motor fibers.

motor neuron, one that carries impulses from the brain or spinal cord to a muscle or gland.

mucous membrane, a form of epithelial tissue which lines the body openings and digestive tract and secretes mucus.

mucus, a slimy secretion of mucous glands.

mulch, a substance placed on or in the soil to retard water loss or to improve soil texture.

multicellular, having many cells.

multiple alleles, one of two or more pairs of genes that act together to produce a specific trait.

mutant, an offspring possessing a characteristic that was not inherited.

mutation, a change in genetic make-up resulting in a new characteristic which may be passed on to offspring.

mutualism, a form of symbiosis in which two organisms live together to the advantage of each.

mycelium, the vegetative body of molds and other fungi, composed of hyphae.

mycologist, a scientist who studies fungi.

mycorhiza, a fungus that lives in a symbiotic relationship with the roots of trees and other higher plants.

narcotics, a group of drugs which result in addiction when used without medical direction.

natural immunity, one which is present in the individual at birth and is not artificially acquired.

natural selection, the result of survival in the struggle for existence among organisms possessing those characteristics that give them an advantage.

nematocyst, a stinging cell in coelenterates.

nephridia, the excretory structures in worms, mollusks, and certain arthropods.

nephron, one of the numerous excretory structures in the kidney, including the Bowman's capsule, glomerulus, and tubules.

nerve, a cordlike structure containing bundles of nerve fibers, or processes.

nerve cell body, the body of a neuron containing cytoplasm and a nucleus.

nerve net, the network of sensory cells in the hydra.

neuron, a nerve cell body and its processes.

neurotoxin, a poison that affects the parts of the nervous system that control breathing and heart action.

neutron, a particle in the nucleus of an atom which carries no electrical charge.

niche, the way in which an organism "earns its living."

nictitating membrane, a thin, transparent covering, or lid, associated with the eyes of certain vertebrates; a third eyelid.

nitrification, the action of a group of soil bacteria on ammonia, producing nitrates.

nitrogen fixation, the process by which certain bacteria in soil or on the roots of leguminous plants convert free nitrogen into nitrogen compounds which the plants can use.

nocturnal, active during the night.

node, a growing region of a stem from which leaves, branches, or flowers develop.

nondisjunction, abnormal segregation of chromosomes.

notochord, a rod of cartilage running longitudinally along the dorsal side of lower chordates and always present in the early embryological stages of vertebrates.

nuclear membrane, a living membrane surrounding the nucleus.

nucleolus, a small, spherical body within the nucleus.

nucleoplasm, the dense, gelatinous living content of the nucleus.

nucleus, the part of the cell that contains chromosomes; the central mass of an atom, containing protons and neutrons.

nymph, a stage between egg and adult in an insect having incomplete metamorphosis.

obligate aerobes, organisms that require atmospheric oxygen for respiration.

obligate anaerobes, organisms that cannot grow in the presence of atmospheric oxygen.

olfactory lobe, the region of the brain registering smell.

olfactory nerve, the nerve leading from the olfactory receptor endings to the olfactory lobe of the brain.

oogonium, an egg-producing cell in certain thallophytes.

ootid, a cell that matures into an egg.

open system, a circulatory system in which the blood is not confined in a continuous system of vessels.

operculum, the gill cover in fish.

opsonin, a blood antibody which prepares bacteria for ingestion by white corpuscles.

optic lobe, the region of the brain registering sight.

optic nerve, the nerve leading from the retina of the eye to the optic lobe of the brain.

oral groove, a deep cavity along one side of the paramecium and similar protozoans.

organ, different tissues grouped together to perform a function or functions.

organelles, specialized structures present in the cytoplasm.

organic, refers to a compound containing carbon, with the exception of CO_2.

organic nutrients, the three classes of foods; carbohydrates, fats, and proteins.

organism, a complete and entire living thing.

origin, the attachment of a muscle at its immovable end.

ornithology, the study of birds.

osculum, an opening in the central cavity of sponges through which water leaves the animal; the excurrent pore.

osmosis, the diffusion of water through a semipermeable membrane from a region of greater concentration of water to a region of lesser concentration.

ossification, the process by which cartilage cells of childhood are replaced by bone cells, resulting in a hardening of the body framework as the organism grows.

ostia, pairs of openings through which blood enters the crayfish heart.

outbreeding, hybridization.

ovary, the basal part of the pistil containing the ovules; a female reproductive organ.

oviduct, a tube in a female through which eggs travel from an ovary.

oviparous, egg-laying animals.

ovipositor, an egg-laying organ in insects.

ovoviviparous, bringing forth the young alive after they have developed without placental connection in the mother.

ovule, a structure in the ovary of a flower which, when fertilized, can become a seed.

oxidation, the union of any substance with oxygen and the resulting release of energy.

oxygen debt, the condition that may occur at times of muscular exertion when enough oxygen may not be supplied to the body and lactic acid accumulates. During a rest period following, some lactic acid is oxidized and some is converted to glycogen.

oxygenation, the process whereby the blood is supplied with oxygen from the lungs.

oxyhemoglobin, hemoglobin with which oxygen has been combined.

oxytocin, a hormone secreted by the posterior lobe of the pituitary gland which helps regulate blood pressure.

palisade layer, a dense tissue in green leaves and twigs consisting of elongated cells.

palmate venation, leaf veining in which the main vains radiate from a central point.

palpus, an appendage of a mouthpart of an arthropod.

pancreas, a gland located between the stomach and intestine which is both endocrine and digestive.

parallel venation, a vein pattern characteristic of the leaves of a monocot.

parasite, an organism that obtains its food entirely from another living thing.

parasympathetic nervous system, a division of the autonomic nervous system.

parathormone, the hormone secreted by the parathyroid glands.

parathyroid, one of the four small ductless glands embedded in the thyroid.

parenchyma, the thin-walled, soft tissue in plants forming cortex and pith.

parietal eye, an organ in the top of the head of the tuatara's head. It does not function as a sense organ.

parotid, one of the pair of salivary glands near the ear.

parthenogenesis, the development of an egg without fertilization.

passive transport, the passage through a cell membrane without the expenditure of energy.

pasteurization, the process of killing and/or retarding the growth of bacteria in milk and other beverages by heating.

pathogenic, disease-causing.

pearly layer, the inner layer of the shell of bivalves.

peat, a substance formed by the decomposition of plants in the presence of water.

pectin substances, jellylike material in the middle lamella of plant cells.

pedicel, the stalk that supports a single flower.

pedipalps, the second pair of head appendages in spiders.

pellicle, a thickened membrane surrounding the cell of a paramecium.

pelvis, the hip girdle, in man consisting of the ilium, ischium, and pubis bones; the central portion of a kidney.

penicillin, an antibiotic produced by a mold; also made synthetically.

pepsin, a digestive enzyme of the gastric juice which changes proteins to peptones and proteoses.

peptone, a stage in protein digestion prior to the formation of amino acids.

percolation beds, gravel stream beds in which water is allowed to flow slowly by releasing it from reservoirs during the summer. They aid in maintaining the water table.

perennials, plants that grow more than two growing seasons.

pericardial cavity, the area in which the heart lies

pericardial sinus, a cavity surrounding the crayfish heart.

pericardium, the membrane around the heart.

pericycle, the tissue in roots from which secondary roots arise.

periderm, the corky layer forming the outer edge of a root after secondary thickening.

periodicity, alternating periods of activity.

periodontal membrane, the fibrous structure that anchors the root of the tooth in the jaw socket.

periosteum, the tough membrane covering the outside of a bone.

peripheral nervous system, the nerves communicating the central nervous system and other parts of the body.

permeable membrane, one that allows substances to pass through it.

petal, one of the colored parts of the flower. (In some flowers the sepals are also colored.)

petiole, the stalk of a leaf.

phage, a bacteriophage, or a virus that reproduces in a bacterium.

phagocytic cells, those that engulf bacteria and digest them with enzymes, including lysozymes.

pharynx, the muscular throat cavity, extending up over the soft palate and to the nasal cavity.

phenotype, the outward appearance of an organism as the result of gene action.

phloem, the tissue in roots and stems that conducts dissolved food substances downward.

photoperiodism, the dependence of some plants on the relation between the length of light and the length of darkness in a given day.

photoreceptor, an organ that is sensitive to light.

photosynthesis, the process by which certain living plant cells combine carbon dioxide and water, in the presence of chlorophyll and light energy, to form PGAL and release oxygen as a waste product.

phototropism, the response of plants to light.

phycocyanin, the blue pigment found in certain algae.

phylum, one of the large divisions in the classification of plants and animals.

physical change, one in which no change occurs in the chemical composition.

physical factors, the nonbiological elements in the environment.

physiology, the study of the functions, or life activities, of living things.

pia mater, the inner of the three membranes of the brain and spinal cord.

pineal body, a gland of undetermined function that lies between the cerebral hemispheres and near the pituitary gland.

pinnate venation, a vein pattern in which the leaves have a single large vein extending through the center of the blade.

pioneers, the first organisms to enter an area that is void of living things.

pistil, the part of the flower bearing the ovary at its base.

pith, a tissue of roots and stems consisting of thin-walled cells and used for food storage.

pith rays, thin cellular layers leading from the pith to the bark in stems of dicotyledons.

pituitary gland, a ductless gland composed of two lobes, located beneath the cerebrum.

placenta, a large thin membrane in the uterus, in the area of the chorionic villi, which transports substances between the mother and developing young by means of the umbilical cord.

plankton, the organisms suspended near the surface in a body of water.

plasma, the liquid portion of blood tissue.

plasma membrane, a thin living membrane located at the outer edge of the cytoplasm.

plasmolysis, the collapse of cell protoplasm due to loss of water.

plastids, living bodies in the cytoplasm of plant cells.

plastron, the lower shell of the turtle.

platelet, the smallest of the solid components in the blood, releasing thromboplastin in clotting.

pleural membrane, one of two membranes surrounding each lung.

plexus, a mass of nerve cell bodies.

plumule, that part of a plant embryo from which the shoot develops.

poikilothermic (**"cold-blooded"**), refers to animals whose internal temperature fluctuates with that of the environment.

polar nuclei, the two structures in the embryo sac in flowers that fuse to form the endosperm nucleus.

pollen grain, the male reproductive structure of flowering plants.

pollen sacs, structures in the anther containing pollen grains.

pollen tube, the tube formed by a pollen grain when it grows down the style.

pollination, the transfer of pollen from anther to stigma.

polyp, one of the stages in the life cycle of coelenterates.

polyploidy, the condition of a plant having some multiple of the diploid number of chromosomes.

pome, an applelike fruit consisting of a ripened receptable surrounding the ovary.

pons, a part of the hindbrain located in the brain stem.

portal circulation, an extensive system of veins which lead from the stomach, pancreas, small intestine, and colon, unite and enter the liver.

posterior, tail, or rear end, of an animal.

potassium-argon clock, a method used to date fossils by measuring the amount of argon—40 present in a rock sample.

population density, the number of individuals of a species in a definite area at a specific time.

population genetics, the study of the frequency of genetic traits in populations

precipitation, the movement of water from the atmosphere to the earth.

precipitin, a blood antibody which causes bacteria to settle out.

predator, any animal which preys on other animals.

premolars, large teeth for grinding.

primaries, in birds, those quill feathers which grow from the end section of the wing.

primary germ layers, the ectoderm, endoderm, and mesoderm.

primary oocyte, the structure in the female gonads that divides to form the secondary oocyte and first polar body.

primary root, the first root of the plant coming from the seed.

prismatic layer, the middle of the shell of bivalves.

proboscis, a tubular mouthpart in certain insects; the trunk of an elephant.

producers, the autotrophs in an environment.

proglottid, a segment of a tapeworm's body.

prolegs, the extra pairs of fleshy legs at the end of the abdomen in caterpillars.

propagation, the multiplication of plants by vegetative parts.

prophase, the stage of mitosis in which chromosomes shorten and split longitudinally.

propolis, a brown substance gathered by bees from the sticky leaf buds of some plants.

prostate, a gland located near the upper end of the urethra in the male. It secretes a fluid which is added to the sperm.

prostomium, a kind of upper lip in the earthworm.

protective coloration, the blending of an organism with the color of its surroundings.

protective resemblance, similarity in shape to something in the environment.

protein synthesis, a universal phase of cell anabolism whereby protein molecules are built up from amino acid molecules.

proteins, a complex tissue-building class of foods containing not only C, H, and O, but also N, S, and usually P.

proteoses, a stage in protein digestion prior to the formation of amino acids.

prothallus, the tiny heart-shaped structure that develops from the spore of the fern.

prothorax, the first segment of an insect's thorax, to which the head and first pair of legs are attached.

prothrombin, an enzyme produced in the liver; it is an inactive part of blood plasma except during clotting.

proton, a particle in the nucleus of an atom that bears a positive electrical charge.

protonema, a filamentous structure produced by a spore in mosses.

protoplasm, organized complex system of substances found in living organisms. It is a colloidal suspension in water.

pruning, the cutting off of surplus branches of trees and shrubs.

pseudopodium, a "false foot" of the ameba or amebalike cells.

ptyalin, a digestive enzyme of saliva which changes starch to maltose; also called salivary amylase.

puberty, the age at which the secondary sex characteristics appear.

pulmocutaneous arteries, those in the frog that branch to the lungs, skin, and mouth membrane.

pulmonary, pertaining to the lungs.

pulp cavity, the area within the dentine of a tooth containing nerves and blood vessels.

pulpwood, timber used for making paper.

pulse, regular expansion of the artery walls caused by the beating of the heart.

Punnett square, a grid system used in computing possible combinations of gametes.

pupa, the stage in an insect having complete metamorphosis following the larva stage.

pupil, the opening in the front of the eyeball, the size of which is controlled by the iris.

pure science, research conducted for the sake of knowledge itself.

pus, collection of dead bacteria and white corpuscles at the site of an infection.

pyloric caeca, pouches extending from the intestine in fish.

pylorus, a muscular valve situated at the junction of the stomach and intestine in vertebrates.

pyramids, conical projections of the medulla of the kidney.

pyrenoid, a small protein body surrounded by starch on a chloroplast of *Spirogyra* and certain other algae.

quadrate bone, the bone in the snake's skull to which the lower jaw is attached.

quarantine, isolation of plants or animals to prevent the spread of suspected infection.

queen, the egg-laying female bee in a hive.

quill feathers, the large stiff feathers in the wing or tail of a bird.

rachis, the axis of quill feathers of a bird.

radial symmetry, the type exhibited by an organism that may be divided into two equal parts by any plane which passes through the diameter of the disk and the central axis.

radioactive, refers to an element that spontaneously gives off particles.

radula, a tonguelike structure in snails which acts as a scraper.

reaction time, the elapsed time between the moment a stimulus is received and a response occurs.

receptacle, the end of the flower stalk bearing the reproductive structures.

receptor, a cell or group of cells that receive a stimulus.

recessive, refers to a gene or character that is masked when a dominant allele is present.

rectum, the posterior portion of the large intestine, above the anus.

red corpuscles, the cells in blood containing hemoglobin.

reduction division, the reduction of chromosomes during meiosis from the diploid number to the haploid number.

reflex action, a nervous reaction in which a stimulus causes the passage of a sensory nerve impulse to the spinal cord or brain, from which, involuntarily, a motor impulse is transmitted to a muscle or gland.

reforestation, the planting of forest trees in an open area from which previous trees have been removed.

regeneration, the ability of organisms to form new parts.

renal, relating to the kidneys.

rennin, an enzyme in the gastric fluid of some mammals which coagulates casein.

replication, self-duplication, or the process whereby a DNA molecule makes an exact duplicate of itself.

reproduction, the process during which plants and animals produce new organisms of their kind.

respiration, the exchange of gases between cells and their surroundings and accompanying oxidation and energy release.

response, the reaction to a stimulus.

retina, the inner layer of the eyeball, formed from the expanded end of the optic nerve.

Rh factor, any one of six or more protein substances in the blood of certain people.

rhizoid, a rootlike growth which carries on absorption.

rhizome, a rootlike horizontal underground stem often enlarged for storage.

rhythmic, refers to regular periodicity.

rickettsiae, a group of organisms midway between the viruses and bacteria in size, that cause disease.

ribosomal RNA, the RNA that is contained within the ribosomes. Its function is not known.

ribosomes, tiny dense granules attached to the endoplasmic reticulum and lying between its folds. They contain RNA and protein-synthesizing enzymes.

rill erosion, the formation of tiny channels as a result of rain water carrying particles of soil down a hill.

rind, the outer covering of a monocot stem, composed of thick-walled hard cells.

ring canals, those that lead through each ray in the starfish to a circular canal in the central disk.

RNA, a nucleic acid in which the sugar is ribose. It is a product of DNA and serves in controlling certain cell activities.

rod, a cell of the retina of the eye that receives impulses from light rays and which is sensitive to shades but not to colors.

root cap, a tissue at the tip of a root protecting the tissues behind it.

root hair, a projection of an epidermal cell of a young root.

root pressure, that which is built up in roots due to water intake and resulting turgor.

rostrum, a protective area which is an extension of the carapace in crustaceans.

row crop, that grown in rows with soil exposed between them.

rumen, the first of the four stomach divisions in the ruminant mammals.

ruminant, a cud-chewing ungulate.

runoff water, rain water that runs off the surface of the ground and enters the drainage system.

saliva, a fluid secreted into the mouth by the salivary glands.

saprophyte, an organism that lives on nonliving organic matter.

sapwood, active tissue in the outer area of wood in a stem.

savannah, a grassland with scattered trees.

scales, the epidermal plates forming the outer covering in fish and reptiles.

scavengers, animals that feed on dead organisms.

scion, the portion of a twig grafted on to a rooted stock.

sclerotic layer, the outer layer of the wall of the eyeball.

scrotum, pouch outside the body that contains the testes.

scutes, the broad scales on the lower side of the snake's body.

secondaries, in birds, those quill feathers that grow from the modified forearm section of the wing.

secondary oocyte, the cell that results from reduction division and develops into the ootid.

secondary root, a branch root developing from the pericycle of another root.

secretion, formation of essential chemical substances by cells.

seed, a complete embryo plant protected by one or more seed coats.

selective cutting, cutting timber trees from a managed forest only when they are mature.

self-pollination, the transfer of pollen from another to stigma in the same flower or another flower of the same plant.

self-preservation, a basic instinct possessed by all animals to stay alive.

semen, fertilizing fluid consisting of sperm and fluids from the seminal vesicle, prostate gland, and Cowper's gland.

semicircular canals, the three curved passages in the inner ear that are associated with the sense of balance.

semilunar valves, the heart valves located at the base of the arteries where they join the auricles.

seminal receptacles, structures that receive sperm cells in certain animals.

seminal vesicles, structures that store sperm cells in certain animals.

seminiferous tubules, a mass of highly coiled tubes within the testes.

sensory nerve, a nerve composed only of the fibers of sensory neurons.

sensory neurons, those that carry impulses from a receptor to the spinal cord or brain.

sepal, the outermost part of a flower, usually green and not involved in the reproductive process.

septum, a wall separating two cavities or masses of tissues, as the nasal or heart septum.

serum, a substance, usually an extract of blood containing antibodies, used in treating a disease after it has struck and to produce immediate passive immunity.

serum albumin, a blood protein necessary for absorption.

serum globulin, a blood protein that contains antibodies.

setae, bristles on the earthworm used in locomotion.

sex chromosomes, the chromosomes that determine the sex of an offspring.

sex-influenced character, a characteristic that is dominant in one sex but recessive in the other, as baldness.

sex-limited character, a characteristic that develops only in the presence of sex hormones, as the beard.

sex-linked character, a recessive character carried on the X, or sex, chromosomes, as color blindness.

sexual reproduction, that involving the union of a female gamete, or egg, and a male gamete, or sperm.

sheath, a capsule surrounding an entire filament of bacteria.

sheet erosion, the loss of a thin layer of soil due to standing water.

shelterbelts, rows of trees planted at intervals to break the force of the wind.

shoot, the first part of the plant visible above ground, formed from the plumule.

sieve plate, in the starfish, the opening of the water-vascular system to the outside.

sieve tube, a conducting tube of the phloem.

silk scar, a tiny point seen near the top of a corn kernel which marks the position where the style was attached.

simple leaf, one in which the blade is in one piece.

simple sugar, a monosaccharide, one which can be absorbed by the body without further simplification, as glucose.

sinoauricular node, a small mass of tissue on top of the heart in which the automatic beat originates.

sinus venosus, a thin-walled sac which is an enlargement of the cardinal vein of the fish and frog, and which lies at the entrance to the heart.

skeletal muscle, that which is striated and voluntary.

slime layer, that which surrounds a bacterium.

smooth muscle, that which is involuntary and found lining the walls of the intestine, stomach, and arteries.

soil, a mass of rock particles and humus from which plants obtain essential materials.

solar plexus, the large nerve ganglion of the sympathetic nervous system located in the abdomen.

solution, a homogeneous mixture of two or more substances.

somatotropic hormone, the hormone secreted by the anterior lobe of the pituitary gland that regulates the growth of the skeleton.

song box, the part of the larynx of birds in which the voice is produced; also called a syrinx.

sori, small clusters of sporangia which appear on fern leaves when they are mature.

species, a group of plants or animals exhibiting the same characteristics and freely interbreeding.

species characteristic, one possessed by all members of a species.

sperm, a male reproductive cell.

sperm nuclei, the two structures formed from the generative nucleus in the pollen grain which function in double fertilization.

spermatid, a structure formed from secondary spermatocytes, which mature into sperm.

spermatocyte, a structure formed by reduction division from a spermatogonial cell.

spherical symmetry, the type exhibited by an organism that may be divided into two equal parts at any point passing through the diameter of the body.

sphincter muscle, a ringlike muscle which closes an opening or a tube.

spicule, the material forming the skeleton of certain sponges.

spinal cord, the main dorsal nerve of the central nervous system in vertebrates, extending down the back from the medulla.

spindle, the numerous fine threads formed between the poles of the nucleus during mitosis.

spiracles, external openings of the insect's tracheal tubes on the thorax and abdomen.

spirillum, spiral-shaped bacterium.

spirochete, a group of spiral-shaped, one-celled organisms resembling both protozoans and bacteria.

spongin, fibers comprising the skeleton of certain sponges.

spongocoel, the central cavity in sponges.

spongy layer, a term applied to loosely constructed tissue with many spaces.

spontaneous generation, a disproved belief that certain nonliving or dead materials could be transformed into living organisms.

sporangiophore, in molds, an ascending hypha bearing sporangia.

sporangium, a structure that produces spores.

spore, an asexual reproductive cell.

sporophyte, the stage that produces spores in an organism having alternation of generations.

sport, a mutant.

spring wood, wood containing many large vessels mingled with tracheids and fibers.

stamen, a part of the flower bearing an anther at its tip.

statocyst, the balancing organ of the crayfish.

stigma, the part of the pistil that receives pollen grains.

stimulus, a factor or environmental change capable of producing activity in protoplasm.

stipe, the stalk of a mushroom.

stock, the plant on which a scion has been grafted; a line of descent; to supply with seed, plants, eggs, or animals.

stolon, a transverse hypha of a mold.

stomata, pores regulating the passage of air and water vapor to and from the leaf.

streaming, the movement of cytoplasm in a cell.

strip cropping, the alternation of strips of row crops and cover crops.

style, the stalk of the pistil.

subclavian vessels, large arteries and veins in the arm area in vertebrates.

sublingual, one of the pair of salivary glands lying under the tongue.

submaxillary, one of the pair of salivary glands lying in the angle of the lower jaw.

subsoil, soil that lies below topsoil and that is usually poor in plant nutrients.

succession, the changing plant and animal populations of a given area.

successive osmosis, the cell-to-cell diffusion of water.

sucrase, a digestive enzyme of the intestinal fluid which changes sucrose to glucose.

summer wood, wood containing few vessels and a large number of fibers.

suspension, a mixture formed by particles that are larger than ions or molecules.

sustained yield, a forest so managed as to give regular crops for cutting.

sweepstakes dispersal, the movement of organisms into new areas despite strong barriers.

swimmerets, appendages on the abdomen of a crustacean.

symbiosis, the relationship in which two organisms live together for the mutual advantage of each.

symmetrical, have a definite shape.

sympathetic nervous system, a division of the autonomic nervous system.

synapse, the space between nerve endings.

synergid, one of two structures formed on either side of the egg in the embryo sac of flowers.

synovial fluid, a secretion of cartilage that lubricates a joint.

systemic circulation, the body circulation as distinct from the pulmonary, hepatic, renal, and coronary circulations.

systems, groups of organs performing similar functions.

systolic blood pressure, arterial pressure produced when the ventricles contract.

tadpole, the larval stage of a frog or toad.

taproot, the main root of a plant, often serving as a food reservoir.

tarsus, the foot of the grasshopper; a bone of the human foot.

taste buds, flask-shaped structures in the tongue containing nerve endings that are stimulated by taste.

taxonomy, the branch of biology which groups and names living things.

teliospore, a two-celled, black, winter spore of wheat rust.

telophase, the last stage of mitosis, during which two daughter cells are formed.

telson, the posterior segment of the abdomen of certain Crustacea.

tendon, a strong band of connective tissue in which the fleshy portion of a muscle terminates.

tendril, a part of a plant modified for climbing.

tentacle, a long appendage or "feeler" of certain invertebrates.

terminal bud, the terminal growing point of the stem.

terracing, the checking of water on sloping land by building level areas to prevent soil erosion.

terrestrial, land-living.

testa, the outer seed coat.

testes, male reproductive organs of higher animals.

testosterone, a male hormone produced in the testes and in the cortex of the adrenal glands in both males and females.

thoracic, pertaining to the chest cavity.

thoracic duct, a vessel carrying lymph and emptying into the left subclavian vein.

thorax, the middle region of the body of an insect between the head and abdomen; the chest region of mammals.

thrombin, a substance formed in blood clotting as a result of the reaction of prothrombin, thromboplastin, and calcium.

thromboplastin, a substance essential to blood clotting formed by the disintegration of blood platelets.

thymus, one of the ductless glands, situated near the breastbone, which begins to atrophy at puberty, and whose function is undetermined.

thyroid, a ductless gland, located in the neck on either side of the larynx, which regulates metabolism.

thyroid hormone, the secretion of the thyroid gland.

tibia, one of the long bones of the lower leg.

tissue, a group of cells similar in structure and function.

tissue destruction, the destruction of cells by pathogenic organisms.

tissue fluid, that which bathes the cells of the body and is called lymph when contained in vessels.

tolerance, an organism's ability to withstand an environmental condition.

tone (muscle), the condition in which flexor and extensor muscles oppose each other, resulting in a continuous state of slight contraction.

topography, the physical features of the earth.

topsoil, that top part of the soil consisting of mineral matter combined with organic matter.

toxin-antitoxin, a mixture of diphtheria antitoxin and toxin, formerly used to develop immunity.

toxoid, toxin weakened by mixing with formaldehyde or salt solution, used extensively to develop immunity to diphtheria, scarlet fever, and tetanus.

trachea, an air tube in insects and spiders; the windpipe in air-breathing vertebrates.

tracheids, thick-walled conducting tubes that strengthen woody tissue.

transfer RNA, the type of molecule thought to deliver amino acids to the template formed by messenger RNA on the ribosomes.

transformation, in pneumococcus, the change from a noncapsulated to a capsulated form, brought about by the transfer of DNA.

transformers, bacteria that change the simpler substances left by the decomposers into nitrogen compounds which are used by plants.

translocation, the movement of dissolved foods in plants.

transpiration, the loss of water from plants.

transpiration pull, one of the forces involved in the rise of water in a stem. As cells lose water to the atmosphere, water enters them from adjacent cells, resulting in upward movement of water.

tree line, the division between low vegetation and the coniferous forest.

trichinosis, the infestation of muscle by encysted trichina worms.

trichocysts, sensitive protoplasmic threads in the paramecium, concerned with protection.

trochanter, a joint in the appendages of the grasshopper which with the coxa forms a ball and socket.

trochophore, a larval form of mollusks.

tropism, an involuntary growth response of an organism to a stimulus.

trypsin, an enzyme of the pancreatic juice which converts protein to peptones and proteoses

tube feet, movable suction discs on the rays of most echinoderms.

tube nucleus, one of the two nuclei present in a pollen grain.

tuber, an enlarged tip of a rhizome swollen with stored food.

tundra, large biome encircling the Arctic Ocean of the Northern Hemisphere.

turbinate, one of three layers of bones in the nasal passages.

turgor, the stiffness of plant cells due to the presence of water.

tympanic membrane, the eardrum.

tympanum, a membrane in certain arthropods, serving a vibratory function.

umbilical cord, that in female mammals leading from the placenta to the embryo.

urea, a nitrogenous waste substance found chiefly in the urine of mammals but formed in the liver from broken-down proteins.

uredospore, a one-celled red, summer spore of wheat rust.

ureter, a tube leading from a kidney to the bladder or cloaca.

urethra, the tube leading from the urinary bladder to an external opening in the body.

uric acid, a waste product of cell activity.

urinary bladder, the sac at the base of the ureters which stores urine.

urine, the liquid waste filtered from the blood in the kidney and excreted by the bladder.

uropod, a flipper, or developed swimmeret, at the posterior end of the crayfish.

uterus, the organ in which young mammals are nourished until they are born.

uvula, the extension of the soft palate.

vaccination, producing immunity by inoculating with a vaccine.

vaccine, a substance used to produce immunity.

vacuolar membrane, a membrane surrounding a vacuole in a cell and regulating the movement of materials in and out of the vacuole.

vacuole, one of the spaces scattered through the cytoplasm of a cell and containing fluid.

vagina, cavity of the female immediately outside and surrounding the cervix of the uterus.

vagus nerve, the principal nerve of the parasympathetic nervous system.

vane, part of a quill feather of a bird.

variations, the differences that occur within the offspring of a given species.

vasa efferentia, tiny tubes in the reproductive system of the frog through which sperm pass into the kidney.

vascular bundles, strands of phloem and xylem tissue found in roots, stems, and leaves of higher plants.

vasopressin, a hormone secreted by the posterior lobe of the pituitary gland which stimulates smooth muscles.

vegetative organs, the parts of a plant that perform all the processes necessary for life except the formation of seeds.

vegetative reproduction, a common method of asexual reproduction in higher plants whereby pieces of the plant tissue are capable of growing into a complete organism.

veins, strengthening and conducting structures in leaves; vessels carrying blood to the heart.

vena cava, a large collecting vein found in many vertebrates.

venation, the arrangement of veins through the leaf blade.

venom, the poison secreted by glands of poisonous snakes or other animals.

ventral, front, or lower (abdominal), surface of animals.

ventricle, a muscular chamber of the heart; a space in the brain.

venules, small branches of veins.

vermiform appendix, a fingerlike outgrowth of the intestinal caecum.

vertebra, a bone of the spinal column of vertebrates.

vestigial organs, those which are poorly developed and not functioning.

viability, the ability of seeds to germinate after dormancy.

villi, microscopic projections of the wall of the small intestine which increase the absorbing surface.

virulent phage, a bacteriophage that produces a lytic cycle of destruction.

viruses, particles that are noncellular and have no nucleus, no cytoplasm, and no surrounding membrane. They may reproduce in living tissue.

visceral hump, the area in bivalves containing the principal digestive organs.

visual purple, the chemical in the rods of the eye necessary for their proper functioning in reduced light.

vitamin, an organic substance, though not a food, that is essential for normal body activity.

vitreous humor, a transparent substance that fills the interior of the eyeball.

viviparous, bearing the young alive, and nourishing them before birth by means of the placenta.

vocal cords, those structures within the larynx which vibrate to produce speech.

vocal sacs, membranous sacs between the ear and shoulder of certain male frogs which serve as resonators and increase the volume of sound.

voluntary muscle, that controlled by the will of the organism.

vomerine teeth, those in the roof of the mouth of the frog which aid in holding prey.

water-borne infections, those produced by certain pathogenic organisms present in water.

water cycle, the continuous movement of water from the atmosphere to the earth and from the earth to the atmosphere.

watershed, a hilly region, usually extending over a large area, which conducts surface water to streams.

watertable, the level at which water is standing in the ground.

water-vascular system, the circulatory system of certain echinoderms.

web membrane, the flexible structure lying between the toes of frogs.

white corpuscles, colorless cells of the blood.

whorled, in stems, having three or more leaves at each node.

wigglers, the larvae of the mosquito.

wildlife, all native animals.

withdrawal symptoms, nervous reactions and hallucinations resulting from the lack of a drug to which the victim is addicted.

woody stem, one containing conducting and supporting tissue that forms layers which are added to year after year.

worker bee, an infertile female bee.

X chromosome, a sex-determining chromosome present singly in human males and as a pair in females.

xanthophyll, a yellow pigment found in certain chromoplasts.

xerophyte, a plant that requires very little water to live.

xylem, the woody tissue of a root or stem that conducts water and dissolved minerals upward.

Y chromosome, a sex chromosome found only in males.

yolk, the part of the bird's egg from which the egg cell obtains its nourishment.

yolk sac, an extraembryonic membrane providing food for the embryo.

zoospores, in *Ulothrix*, the flagellated cells that leave the mother cell and later develop into new organisms.

zymase, the enzyme system in yeast cells that acts on sugar to produce carbon dioxide and alcohol.

INDEX

Page references for illustrations are printed in *italics*.

Abalones, 402
Abdomen, Crustacea, 412; grasshopper, 427–*428;* insect, 423
Abdominal cavity, 552, 576
Abert squirrel, 192, *193*
Abiogenesis, 19, 22–25
Abscission layer, leaf, 346, *347*
Absorption, of alcohol in body, 630; cellular, 57, 72–79; in intestines, 578–579; by roots, 320–322; *see also* Diffusion
Acetic acid, *4*
Acetobacter, 232
Acetylcholine, 613
Acorn worms, 453
Acromegaly, 642
ACTH, 642
"Adam's apple," 601
Adaptation, 30–31; to environment, 190–191, 192
Adder, 498
Addison's disease, 643
Adenine, 50, 96, 142
Adenoids, 593
Adolescence, 641, 644–646
ADP, in photosynthesis, 87, 89; and respiration, 100–101
Adrenaline, 643
Adult, in insect metamorphosis, 424, 434
Adventitious roots, 318, *319*–320
Aeciospores, 271
Aedes mosquito, 443
Aerial roots, 318
Aerobes, 228
Afferent branchial artery, 467
African elephant, 530
Afterbirth, 656
Agar-agar, 287–288
Age, chronological and mental, 166
Agglutination, of red blood cells, 586, *587*
Agglutinins, 244
Agglutinogens, 161–162
Agnatha, 459
Air, and bird flight, 509; breathing and, 603–605; gases in, 40–41; and malaria, 3; movement of, 672–677
Air bladder, 468
Air sacs, of bird, 516; human, 601, 602
Albino, 166; corn, *147;* fawn, *187*
Albumen, 518, 569
Alcohol, 77; body and, 630–633; fermentation and, 100, 222–223, 228–229, 270
Alcoholics Anonymous, 632
Alcoholism, 631–633
Alfalfa, 667, 668, 713, 714, 716
Algae, 90, 277–290, *285;* cellular division, 107–108; and giant clam, 402; and space travel, 289, 610
Alimentary canal, 479, 571, 575, 576
Alkalinity, 673–674
Allantoic duct, 655
Allantois, 654
Alleles, 122, 127, 139, 148; multiple, 161–162, 165; recombination of, 189; and Rh factor, 162
Alligators, 501, 502
Alpha particles, 36
Alternation of generations, 286, 359
Altitude, climate and, 700, *701;* and respiration, 609–610
Alveoli, 601, *602*
Ambergris, 529
Ameba, 28, 255–*256,* 694, (Table) 261
Amebocytes, 376
Ameboid movement, 254
American hellbender, 474
Amino acids, *47*–48, 57, 96–98; in body, 568; gastric fluid and, 577; and genetic code, 142–143; intestinal fluid and, 577–578; in *Neurospora,* 150–152
Amino group, 47
Ammonia, and nitrogen cycle, 667, 669
Ammonification, 667
Amnion, of birds, 518; human, 654, 655, 656; of reptile egg, 489
Amniote egg, of reptiles, 489
Amphibians, 455, 472–486
Amphioxus, 453
Amylase, 367, 577
Anabaena, 278, 279
Anabolism, 94
Anaerobes, 228
Anaerobic, bacteria, 232, 669, 676; respiration, 100, 228, 229, 270, 607
Anal, fin, 465; opening, human, 576, 579; pore, of paramecium, 258
Anaphase, mitosis, 104, 106; meiosis, 112
Anatomy, comparative, 413; definition, 12; of frog, 477, *488;* human, *584–585*
Anemia, and hookworms, 391
Anesthetic effect on cells, 77
Angiosperms, *304,* 306–311, (Tables) 308, 309; reproduction in, 352–369
Animals, breeding of, 170, 178–180; cold-blooded, 485, 491, 496, 674–675; in coniferous forest, 702; decay of, 232; in deciduous forest, 703; in desert, 705; diurnal and nocturnal, 685–687; estivating, 485, 688; flesh-eating, *530*–531, 677–678; fur-bearing, 737; grassland, 704; hermaphroditic, 387; hibernating, 688; marine, 707–708; migration of, 190–191, 688–692; night vision of, 627; in rain forest, 706; and seed dispersal, 361; soil and, 231; tundra, 701; vertebrate and invertebrate, 374–375, 452, 453; warm-blooded, 507, 512, 674–675
Annelids, 393–396, 400, 417, (Table) 410
Annual, rings, 330; rhythms, 693
Annuals, 310, 311, 325; seeds of, 366
Annulus, of mushroom, 274
Anole, 500
Anoxia, 610
Anteaters, 523, 524, 528
Antelope, 531, 532
Antennae, of crayfish, 412, 414; of grasshopper, 429; of spiny lobster, 416
Antennules, of crayfish, 412
Anterior horns, 616–617
Anther, 352, 356; and pollen formation, 354–*355*
Antheridium, fern, 300–301; moss, 295–297; in *Oedogonium,* 284
Anthocyanins, 62–63; in leaves, 346
Anthrax, immunization against, 246; Koch and, 238–239
Antibiotics, 3, *250*–252
Antibodies, 243–244, 453; against polio, 6–7; Rh factor and, 587
Antigens, 243–244, 587
Antipodals, 356
Antitoxins, 244; diphtheria and, *248*–249
Ants, 438–439
Anus, earthworm, 393; fish, 466; grasshopper, 428; mollusk, 400, 401; roundworm, 391; starfish, 406
Aorta, fish, 466; grasshopper, 429; human, 589, 590, 591, 593, 595
Aortic arches, 395, 480
Apes, 532
Apical cell, 280
Apical dominance, 328, 329
Apoda, 474
Appendages, arthropods, 410; crayfish, 412–413, 416; insect, 432; jointed, 432; spider, 420
Appendicitis, 576
Aqueous humor, 625, 626
Arachnida, 419–421
Arachnoid mater, 613
Archaeopteryx, 506, *507*
Archegonium, 295, 300–301

Archeozoic era, 222
Arctic region, 700, 701
Arginine, 97, 151–153
Argon-40, 544
Aristotle, 199
Armadillos, 528
Arsenic, syphilis and, 249
Artemia, 417
Arteries, *590*, 591; coronary, 590, 593; fish, 466, 467–468; frog, 480–481; pulmonary, 589, 591, 593, 602, *603*; renal, 481, 593, 595–596
Arterioles, 591, 595–596
Arthropods, 410–421
Ascaris, 131, 390, *391*
Ascomycetes, 266, 269, 270–271
Ascus, 266, 270
Aspergillus, 268
Assimilation, 27
Association areas, of cerebrum, 615
Asters, 105, 107
Asymmetrical organisms, 395
Atmosphere, carbon-oxygen cycle in, 665–667, *666*; and life, 676–677; nitrogen cycle and, 667–669, *668*; oxygen in, 665–667, *666*; water cycle in, *664*–665
Atoll, 382
Atomic, mass, 35, 36–37; number, 35, 36; particles, 35; weight, 36
Atoms, 34, *35*–39
ATP, 561, 566; in photosynthesis, 87, 89; and respiration, 99, 100–101
Atrioventricular, node, 563; valves, 588–589, 590
Atrium, bird, 517; fish, 466; frog, 480, 481; human, 588, 590, 593
Auditory, canal, 622; nerve, 623, 624
Audubon, 735
Aurelia, *381*
Auricles, 466, 480
Australia, marsupials in, 196, 524
Australoid type, *547*–549
Australopithecus, 544
Autonomic nervous system, 612, *618*, 619
Autosomes, 136, 137, 141
Autotrophs, 91, 94, 677; euglena as, 260–261
Auxins, 322, 328, 358
Averages, breeding ratios as, 127–128
Avery, Oswald T., 144
Avocado pear, 355
Avoiding reaction, of paramecium, *258*
Axil, 326
Axillary buds, 326
Axolotls, 475
Axons, 612, 613

Backbone, 374–375, 453
Bacteria, 3, 28, 222–235, 238; anthrax, 238–239, 245; cellular division, 107–108; chemosynthetic, 91–92; diphtheria, 248; in lymph, 594; and nitrogen cycle, 667, 668–669; as pioneers, 694; related organisms, 235–236; saprophytic, 681; as transformers, 678
Bacteriochlorophyll, 84, 228
Bacteriology, 2, 222–223, 238–239
Balance, biological, 669–670; in endocrine glands, 646; homeostatic, 70–71; sense of, 615, 623–624; upset by man, 723
Bald eagle, *735*
Baldness, 139, 164
Ballooning, 420
Barberry, 271, *272*
Barbiturates, 635
Barbs, of feather, 509
Barbules, of feather, 509
Bark, 330–332; tannic acid from, 731
Barnacles, 417–418
Barriers, to dispersal, 700; evolution and, 192–193
Basal, disks, 378; metabolic rate, 608; metabolism, 608
Base triplets, 96–98
Bases, DNA, 50–51, 95–96, 142–143; RNA, 96
Basidia, of mushroom, 274
Basidiomycetes, 271–275
Basidiospores, 271, 273, 274
Basidium, 271, 273
Bats, 525
Beadle, George W., 150, *151*–153
Beak, bird, 506, 512, *514*, 515; turtle, 503
Bean, embryo, 369; plant, *308*; seed, 362–*363*; as food, 569
Bean seedling experiment, 10–11
Beards, 164–165
Bears, *200*, 531; winter and, 688
Beavers, 525, *526*
Beebread, 437
Beetles, 440
Behavior, vertebrate, 455–457
Benthic zone, ocean, 707
Beta particles, 36–37
Bicuspids, 574
Biennials, *310*, 311
Big Tree of Tule, 306
Bilateral, larva, 404, *405*; symmetry, *385*–386
Bile, bird, 516; frog, 479, 481; human, 575, 577, 598
Binomial nomenclature, 200
Biochemical similarity, classification and, 204
Biogenesis, 18, 19, 25
Biogeography, defined, 699
Biology, definition, 2; development, 2–5; specialized branches, 12
Biomes, coniferous, 702–703; deciduous, *703*; desert, 704–*705*; fresh-water, 708–*709*, grassland, 703–*704*; marine, *707*–708; rain forest, 705–707, *706*; tundra, 701–*702*
Biosphere, 660
Biosynthesis, 44
Birds, 506–520, *508*, *513*; conservation of, 734–737; migration of, 690–692, *691*; and seed dispersal, 362
Birth, human, *655*–656; Rh factor and, 587
Bison, 532, 723, 737–*738*
Bivalve mollusks, 401–402
Bladder, urinary, 482, 595, 596
Blade, leaf, 341–343
Blastocoel, 653
Blastula, 653
Blind spot, 626
Blinking, 455
Block cutting, 727
Blood, at birth, 656; circulation, 2; in crayfish, 414; in earthworm, 394–395; in fish, 466–468; in frog, 480–481; and gamma globulin research, 6–7; human, 581–594; leeches and, 396; in lungs, 602; mosquito and, 442; oxygenated, 467, 468, 480, 535, 582, 593, 602; and pneumonia, 144; serum from, 249
Blood type, 586; inheritance and, 160–162, (Table) 163
Blood vessels, in earthworm, 395; human, 591–592; in small intestine, 579
Bloodsuckers, 396
Blue babies, 656
BMR, 608
Body cavity; *see* Coelom
Bonds, 38; covalent, 38–39, 40; chemical, 40, 99; double, 44; ionic, 39; triple, 44
Bones, 455; of birds, 510; human, *556*–560, *557*; in middle ear, 623
Bony, fishes, 462–470; layer, 557, 560; skeleton, 462
Botulism, 228, 240
Boveri, Theodor, 131
Bowman's capsules, 595, 596
Brace roots, 318
Bracket fungi, 274–275
Braford cattle, 180
Brahma poultry, 178
Brahman cattle, 179–180
Brain, 6; alcohol and, 631, 632; bird, *536*; fish, 468–469, 535, *536*; frog, *482*, *536*; grasshopper, 429; human, *584*–*585*, 613, *614*–*616*; insect, 432; mammal, 535–*536*; of primates, 532; reptile, *536*; vertebrate, 468–469, 535, *536*
Branching, of stems, 328–329
Brangus cattle, *179*
Breastbone, of birds, 510
Breathing, of aquatic mammals,

528–529; of birds, 516; of crocodilians, 501; of frog, 480; human, 600–610
Breeding, animal, 170, 178–180; plant, 170–178
Breeding ratios, 127–128
Bridge, turtle shell, 504
Bridges, C. B., 139–140
Bridges, Calvin, 134
Bronchi, 516, 601, 603
Bronchial tubes, 601
Bronchioles, 601, 602
Bronchitis, smoking and, 637
Brood comb, of bee, 437
Brownian movement, 226
Bruises, 586
Bryophyta, 294
Bud scales, 325
Bud-scale scars, 326
Budding, 108; and grafting, *337;* in hydra, 380; in sponges, 377; in yeasts, 269–270
Bud-mutants, 176
Buds, on plant stems, 325–326, 337
Bugs, 423, 426, 440
Bulb, of potato, 335
Bulbus arteriosus, of fish, 466
Bulk feeders, 680, 681
Bundle scars, 325
Burbank, Luther, 170–*171,* 173, 174–176
Bureau of Entomology and Plant Quarantine, 443
Bursa, 561
Bushmaster, 498
Butter, 568; bacteria and, 233
Buttercup root, *316*
Butterflies, 433–*434, 682,* (Table) 435; migration of, *689*–690; pollination and, 356

Cabbage, 177, 178
Cacti, *675,* 676
Caecilians, 474
Caecum, 576
Caimans, 501, *502*
Calcium, and blood clotting, 583; in body, 566; compounds, in bones, 556; parathormone and, 641, 646
Calcium-40, 544
Calluses, 596
Calories, 566
Calorimeter, 608
Calyx, of flower, 352, 359
Cambium, cork, 331; layer, 308; vascular, 327, 332
Camels, 190–*191,* 531, 532
Camera, eye and, *627*
Camouflage, 463, 681–683
Cancer, smoking and, 637; viruses and 219–220
Canine tooth, 573
Canning, of foods, 234
Cap, of mushroom, 274; root, *314*
Capillaries, fish, 466, 467–468; human, *590,* 591, 593, 596, 602
Capillarity, 337–*338*
Capillary action, of ground water, 665
Capsule, of bacterial cells, 224; mosses, 295–297
Carapace, crayfish, 415; Crustacea, 412; turtle shell, 504
Carbhemoglobin, 582
Carbohydrates, 63; chemosynthesis and, 91, 92; chloroplasts and, 61; as food, 565, 566–568; nature of, 44–46; synthesis, 94; *see also* Photosynthesis
Carbon, 43–44; atom, *35,* 36, *39;* and photosynthesis, 86, 88–89
Carbon dioxide, 43, 665, 666–667; acceptor, 88, 89 and breathing, 602; and fermentation, 100, 229, 270; formation, 39–40; in leaves, 346; molecule, *39;* and photosynthesis, 84, 86, 88–89, 90, 346, 347; poisoning, 609; and respiration, 99–100; and sponges, 376
Carbon-14, 85, 86, 543
Carbon-oxygen cycle, 665–667, *666*
Carbonic acid, roots and, 314
Carboniferous period, 298, 304; reptiles in, 489
Carboxyl group, 47
Cardiac muscle, *562,* 563
Caribou, 531, 532
Carnivores, *530*–531, 677–678, 687
Carotenes, 61; in leaves, 345–346
Carotid arches, of frog, 480
Carrel, Dr. Alexis, 28–29
Carriers, of disease, 240–241
Carrion eaters, 512, 513
Carrot root, *317*
Cartilage, 556
Casein, 569
Cassowary, *511*
Cat family, 530
Catabolism, 94, 98
Catalysts, 48; chlorophylls as, 83–84; enzymes as, 95; vitamins as, 571
Caterpillar movement, of snake, 495
Caterpillars, 424, 434, 439
Cattails, 672
Cattle, breeding of, 178–180
Caucasoid type, 547
Caudal fin, 465, 483
Caudata, 474
Cavities, brain, 614
Cell sap, 62
Cells, 5; defenses against disease, 243; division (human), 652–653; division of labor, 374; environment and, 70–79; growth and reproduction, 103–112; in human body, 551; interdependence, 374; and living organisms, 26; metabolism, 94–101; multicellular organisms, 374; parts of, 57–65, *59, 61;* processes of, 56–57; red blood, 582, 586–587; somatic, 134, 136, 141; specialization, 65–66, 71, 374, 394; viruses and, 214, 215–216; white blood, 582, 583
Cellular organization, 26; classification and, 204
Cellulose, 45–46, 63; in digestive system, 568; molecules, in telophase, 107; termites and, 439–440, 681; in trees, 728
Cementum, 574
Cenozoic Era, birds in, 506–507 lobed fins and, 472; mammals in, 195, 522; ungulates in, 532
Centipedes, 410, *418*–419
Central, cylinder, root, 316; nervous system, 612; neurons, 612, 618
Centrifuges, 56, 64
Centrioles, 105
Centromeres, 106
Cephalization, 387
Cephalopods, 403–404
Cephalothorax, 412
Cereals, 566
Cerebellum, bird, 517; fish, 468; frog, 482; human, 615, 624; mammal, 536
Cerebral hemispheres, of vertebrates, 535–536
Cerebrospinal fluid, 614
Cerebrum, 455; alcohol and, 631; bird, 517; fish, 468–469; frog, 482; human, 614–*615,* 624, 625; vertebrate, 535–536
Cervix, 650, 655
Cestoda, 386, 389–390
Cetaceans, 528–529
Chambered nautilus, 403–404
Chameleon, 500
Characteristics, acquired, inheritance of, 185; chromosomes and, 132–133; inherited, 116, 131; *see also* Inheritance; Traits
Cheese, 568, 569; bacteria and, 233; molds and, 268
Chelipeds, 413, 416
Chemical, bonds, 40, 99; change, 33, 40; control of insects, 445–446; cycles, 232–233, 664–669; defenses against disease, body's, 243–244; energy, 34, 94, 98–101; equation, 39; food preservatives, 234; organization, of living things, 52; phase of digestion, 576–578; reactions, 34, 37, 39–40, 49, 84–89, 94, 347; symbols, 34
Chemistry, biology and, 3
Chemosynthesis, 91–92
Chemosynthetic bacteria, 228

Chemotherapy, 3, 249
Chemotropic bacteria, 228
Chick embryos, incubation temperature, *8*
Chicken heart muscle experiment, 28–*29*
Chickens, 518; *see also* Poultry
Chigger, *421*
Chilopoda, 418, 419
Chimpanzee, 532
Chiropterans, 525
Chitin, 410, 414, 426
Chlorella, *85*, 281; photosynthesis and, 85; and space travel, 289, 610
Chloroform, 77
Chlorophylls, 61, 62, 91; in algae 277, 279, 286–287; in leaves, 343, 345–346; and photosynthesis, 82, *83*–84, 87
Chlorophyta, 280
Chloroplasts, 61, 62; in euglena, 260; in leaves, 343, *344;* of *Oedogonium*, 283; and photosynthesis, *82*–83, 84, 85, 87, 88–89; of *Spirogyra*, 281–282
Cholera, 228
Cholesterol, 47
Cholinesterase, 613
Chondrichthyes, *456*, *461*–462
Chordata, 452–453
Chorion, 654
Choroid layer, 624
Chromatids, 105, 110, 112, 141
Chromatophores of fishes, 463
Chromoplasts, 61–62
Chromosomal aberrations, 146
Chromosome number, 109–110, 176–177; in algae, 284, 286; human reproduction, 648, 649, 652; in mosses, 296–297; in plants, 354, 355, 356, 358
Chromosomes, 49, 57, 58; of fruit fly, 136, 155–156; genes and, 120, 126, 132–134; homologous, 110–112; human, 137, 146, 155–*156;* mitosis and, *104*, 105, 106–107, 112; and Mongolian idiocy, *167*–168; mutations and, 146, 189; recombination of, 189
Chrysalis, of butterfly or moth, 434
Chrysophyta, 286
Cicada, 440–441
Cilia, 387, 388; in human trachea, 601; of mollusks, 401; of paramecium, 257; of trochophore larva, 400
Ciliary muscles, 624
Ciliates, 694
Ciliophora, 257
Circular muscles, of earthworms, 394
Circulatory system, bird, 517; in crayfish, 414; of fish, 466–*467;* of frog, 480–481; of grasshopper, 429; human, 581, 589–598, *592;* in mammals, 534–535; vertebrate, 454
Cirrhosis, 631
Citrulline, 151–153
Citrus fruits, mold on, 268
Clams, 399, 401, *402;* starfish and, 405–406
Classes as Linnaean grouping, 204
Classification, 199–207, (Tables) 202–203; phylogenetic tree and, 406–608; vertebrates, 374–375
Claws, in carnivores, 530
Clay, 673
Cleavage, of cytoplasm, 104, 107; furrow, 107
Climate, forests and, 731
Climatic, barriers, 700; zones, 700, *701*–707
Clitellum, of earthworm, 394, 396
Cloaca, bird, 517; frog, 479, 482, 483; turtle, 503
Clotting of blood, 566, 581, *583*–586, (Table) 586
Clover, 667–669, 713, 716
Club mosses, *301*
Coal, 299
Coca plant, 634
Cocaine, 634
Cocoon, of butterfly or moth, 434; of earthworm, 396; of spider, 420
Codeine, 634
Coelenterates, 377–382, 385, 386
Coelocanth, 472
Coelom, 407–408; of human embryo, 653
Coenzymes, 49, 87, 91
Cohesion, and water rise, 338
Colchicine, 177, 178
Cold, deserts, 704, *705;* receptors, 619–620
Coleoptera, 440
Collar cells, 376
Collarbone, of birds, 510
Collecting tubule, 595
Colloids, 42, 72, 577
Colon, frog, 479; grasshopper, 428; human, 576, 579, 598
Colonial organisms, 65, *66*
Colonies, algae, 277, 278
Color blindness, 139, 162–*163*, *164*
Coloration, of fishes, 463; of moths, 190; protective, 681; of toad, 476
Comb, of bee, 437
Combustion, 98
Communities, biotic, 693–697
Companion cells, bark, 332
Competition, 186–187, 230, 662
Complemental air, 605
Compost, 715
Compound, eyes of crayfish, 412, 414; leaf, 342, 343; microscope, *13*–15
Compounds, 38–40; inorganic, 43; mineral, 43; organic, 43–48
Computers, 10
Concave cell, algae, 280
Concentration, molecular, 73, 75
Conches, 402
Concussion, 614
Conditioned reactions, 457
Condor, *735*, 736
Cones, of eye, 625–627; pine, 304, 305–306
Conifers, 305, *306*, (Table) 306
Conjugation, in bread mold, 267–268; in paramecium, *259;* in *Spirogyra*, *281*, 282
Conservation, bird, 734–737; fish, 732–734; forest, 732–734; importance of, 712; mammal, 737–739; soil, 712–718; water, 718–720
Constrictors, 493–*494*, 497
Consumers, food, 677–678
Contour, farming, 716; feathers, 508–509
Contraction, of heart muscle, 590; muscle, *561*, *562*, 615; of stomach, 575
Control, in experiment, 9, 10–12; of insects, 443–448, 727–728
Conus arteriosus, of frog, 480
Convolutions, of cerebrum, 614
Copepods, 418, 708
Coracoid bones, of birds, 510
Corals, 376, 378, 381–382
Cork, 308, 330–331
Corm, 335
Corn, as food, 569; gene mutations in, 188; hybrid, *172*, 173, *174*, *175;* seed (kernel), *363*–364, 366, *368*, 369; smut, 272, 273
Cornea, 624 625, 626
Cornish poultry, 178
Corolla, of flower, 352
Corpus luteum, 651
Correns, 132
Corridor, land, 190
Cortex, of adrenal glands, 642–643, 644; bark, 331; of cerebrum, 614–615, 631; kidney, 595; plant, 308; root, 315; stem, 334
Cortin, 642–643
Cortisone, 643
Cotyledons, 306, 362; of bean seed, 362, 363, 368–369; corn kernel, 363–364, 366, 368–369
Cougar, 200, 530
Countershading, 463, *682*
Cow, 531, 532
Cowper's gland, 648–649
Cowpox, 245
Coxa, of grasshopper, 427
Coyote, 530
Crabs, 410, 416
Cranial cavity, of bird, 517; of

fish, 468; human, 552; of mammals, 536, 622, 625
Crayfish, 410, 412–416, *413*, *414*
Cretaceous period, birds in, 596; crocodilians in, 501; marsupials in, 524
Cretinism, 640
Crick, Francis H. C., *49*, 50
Cricket, *430*
Cristae, 60
Crocodilians, 501–*502*
Crop, of bird, 513–516; of earthworm, 394; of grasshopper, 428
Crops, cover and row, 713, 714; disease-resistant, 171, *172*
Cross-pollination, 173–174, 356; of pea plants, 117
Crosses, blood types and, 162; diagramming, 122; dihybrid, 124–126, *125;* of garden peas, 118–120; monohybrid, 122–124, *123*, 162; of plants, 173–176, *175*
Crossing over, ***141***
Crown, of tooth, 574
Crustaceans, 412–418, 677, *678*
Cryptomonads, 287
Cud, 532
Culex mosquito, *262*, 443
Cup fungus, 270
Cuspid tooth, 574
Cuticle, of earthworm, 395; of flukes, 388; of leaf, 343; of parasitic worms, 388
Cuttings, 177
Cyanophyta, 279
Cycads, 304
Cycles, chemical, 232–233, 663–669; lysogenic, 219; lytic, 216–217; ovarian and uterine, 650–651; in photosynthesis, 89; *see also* Rhythms
Cyclostomata, 459
Cylinder, central of root, 316
Cysts, of parasitic worms, 389, 390, 382
Cytolysins, 244
Cytoplasm, 57–63, 83, 94, 96; centrioles in, 105; cleavage of, 104
Cytosine, 50, 96, 142

Dairy industry, bacteria and, 234
Dams, 719, *720;* fish and, 733
Dark reaction, of photosynthesis, 86, 88–89
Dart, Dr. Raymond, 544
Darters, 468
Darwin, Charles, 185–187, 188, 504, 542–543
Dating, fossil, 543–544
Daughter cells, 103–104, 107; in bacteria, 225; in paramecium, 259; in plant ovule, 356; in pollen sac, 354–355; in yeast, 269–270
DDT, 445–446, 727
Deamination, 569
Decay, 232, 667
Decomposers, 678
Deer, 531, 532; restoration, 738
Defenses against disease, 242–244
Degeneration, of parasitic worms, 388
Dehydration, 565; of food, 234
Dendrites, 612, 621
Denitrification, 669
Density studies, of population, 661–662
Dentine, 574
Deoxyribonucleic acid, 50–52; *see also* DNA
Deoxyribose sugar, 50, 51; units, 142
Depletion, of ground water, 718–719; of soil minerals, 713–714
Depressant, alcohol as, 631
Dermis, human skin, 596
Descent of Man, The, 542
Desert region, 686–687, 700, 704–*705*
Desmids, 286
Deuterium, *36*
Deuteromycetes, 275
Devonian period, 454, 472; fishes in, 462–463
DeVries, Hugo, 132, 187, 188
Dextrose, and nutrition, 568
d'Herelle, F. H., 216
Diabetes, insipidus, 642; mellitus, 166, 643–644
Diaphragm, human, 552, 601, 603, 604
Diastole, 590
Diatomaceous earth, 287
Diatomic molecules, 38
Diatoms, 286–287, 376
Dicots, (Table) 309; flowers of, 354; leaves of, 341; seeds of, 362, (Table) 364; stems, 333–334, *335*
Diet, carbohydrates in, 566–568; vitamins and, 571
Differentially permeable membrane, 72, 75, *76*
Diffusion, *72*, 73–78, *74*, *75;* successive osmosis and, 320–321
Digested foods, in blood, 581
Digestion, in ameba, 255; cellular, 57; in crayfish, 414; in grasshopper, 428; in humans, 571–579, (Table) 578; in hydra, 379–380; in paramecium, 258; in planarians, 387; in roundworms, 390–391; in sponges, 377; in starfish, 405–406
Digestive enzymes, 57, 568, 571, 576–578; of bacteria, 227–228
Digestive system, of bird, 513–516; of earthworms, 394–395; of fishes, 465–466; of frog, 479; of roundworms, 390–391; vertebrate, 454
Dihybrids, 125–126, *125*
Dinoflagellates, 287
Dinosaurs, *490*–491
Diphtheria, 228, 247–249
Diploid chromosome number, 110, 112, 120, 176; human, 648, 652; mosses, 29; plants, 356, 358; and sex chromosomes, 136
Diplopoda, 418, 419
Diptera, 441–443
Disaccharides, 45, 89; and nutrition, 568
Disease-resistant crops, 171, *172*
Diseases, alcoholism, 631–633; diphtheria, 228; fungi and, 271–273, 275; housefly and, 441; infectious, 5, 238–252; inherited, 166; protozoans and, 262–263; smoking and, 637; viruses and, 212, 213–214, 215, 219–220; vitamin-deficiency, 569, 631
Dispersal, of animals and plants, 699–700; barriers to, 700; man and, 699–700; sweepstakes, 193
Distillation products, 729–730
Diurnal organisms, 685–687
Division, cell, 103–112; in bacteria, 229–230, 231; rate of, 107
Division of labor, among bees, 436–437; cellular, 66, 374; among insects, 432
Division plate, 107
DNA, 57, 566; bacteria, 225; bases in, 50–*51*, 95–96, 142–143; and cancer, 220; control of cell activities, 52, 58, 63; genes and, 142–146; phage, 216, 217–219; proof of, 143–144; and protein synthesis, 95–98; replication, 51–52, 104–105; structure of, 50–52, *51;* in virus core, 214
Dodo, 511
Dog family, 530–531
Dolphins, 528, 529
Domagk, Dr. Gerhard, 249
Dominance, incomplete, *126–127*, *128;* Mendel's law of, 120, 135; and nondisjunction, 139–141; principle of, 117–120
Dominant characteristics, 120, 122, 123–124; genes, 157–159
Dormancy, 688; in seeds, 366
Dormant plants, 674
Drainage, mosquitoes and, 447
Drone bee, 110, *436*, 437
Droplet infection, 241
Drosophila, 134, 135, 140–142, *149; see also* Fruit fly
Droughts, 718–719
Drugs, antibiotics, *250*–252; barbiturate, 635; colchicine,

176, 177; narcotic, 634–635; prontosil, 249; salvarsan, 249; sulfa, 250; thiouracil, 640
"D. T.'s," 632
Duckbilled platypus, 523, *524*
Ducks, 510, 512, 518
Ducts, bile, 576; and digestion, 571–572, 573; lymphatic, 593, *594;* pancreatic, 576
Ductus arteriosus, 656
Dujardin, 55
Duodenum, 575, 576
Dura mater, 614
Dwarfism, 640–641, 642
Dysentery, amebic, 263

Eardrum, of frog, 478; human, 622, *623*–624
Ears, bird, 517; fish, 464, 469; frog, 478; human, 622–624, *623;* snake, 493, 496
Earth, age of, 182; shape of, 3–4
Earthquakes, *663*, 664, 697
Earthworms, *393*–396, *394*
Echinoderms, 404–406; symmetry, 385
E. coli, 231
Ecology, 660–711; definition, 12, 660; *see also* Environment
Ecosystems, 660–*661*, 662, 672, 677–680; in jar, 694–695
Ectoderm, of human embryo, 653; of hydra, 378, 380; in worms, 386
Ectoplasm, of ameba, 254
Edentates, 528
Eft, red, 474
Egg (ovum), 109, 110, 111–112, 131, *132;* of amphibians, 537; bee, 436, 437; bird, 518–520, *519;* crayfish, 415; of duck-billed platypus, 523; earthworm, 396; fish, 469–470, 537; of flowering plant, 356, 357; frog, 482, *483;* grunion, 692–693; human, *132*, 159, *649*–650, 651–652; in insect metamorphosis, 424, 434; of *Oedogonium*, 284; of pea plants, 117, 120; reptile, 489, 537; of spiny anteater, 523; turtle, 503
Ehrlich, Paul, 2, 249
Elasmobranchii, 461
Electrical charge, and ion penetration of membrane, 77
Electrolytes, 41
Electron beam, 15–16
Electron cloud, 37
Electron microscope, 4–5, *13*, *15*–16, 56; viruses and, 212–213
Electrons, 35, 37–38, 87; transfer, 38–40
Elements, 35–39; heavy, 85, 86; in living organisms, 42–43, (Table) 42
Elimination, bird, 517; crayfish, 414; earthworm, 394; fluke eggs and, 388; grasshopper, 428; hydra, 380; planarian, 387; in sponges, 377; in starfish, 406; and tapeworms, 389–390
Elk, 521, 532, 688
Elongation region, root, *314*, 315
Embryo sac, flower, 356–358
Embryology, 182–184
Embryos, bird, 518, *519;* comparison, 182–184, *186;* corn, 365–366, 369; of fish, 469; human, 652–655, *654;* of mammals, 537; marsupial, 524; plant, 358–359, 362–364, 369; skeleton of human, 556
Emphysema, smoking and, 637
Emu, *511*
Emulsion, 577
Enamel, of tooth, 574
Encephalitis, 443
Enders, Dr. John F., 6
Endocrine system, vertebrate, 454
Endoderm, of human embryo, 653; of hydra, 378, 379, 380; in worms, 386
Endodermis, root, 315
Endoplasm, of ameba, 254–255
Endoplasmic reticulum, 57, 60, *63*
Endoskeleton, human, 552–556, *545, 555;* of vertebrates, 452, 454
Endosperm, of corn seed, 362, 364; of plant, 358–359; nucleus, of plants, 358
Endospores, bacterial, *230*–231
Endotoxins, 242
Energy, 33–34, 40, 73, 94; body, 566, 568; from chemosynthesis, 91–92; food chains and, 678–680; as fuel for life, 81–82; levels, of electrons, 38, 87; of plants, 348; release in body, 607–608; requirement of living things, 26; respiration and, 98–101; transfer through photosynthesis, 82–90
Entomology, 423
Environment, 12, 30; adaptations to, 190; and algae reproduction, 286; balance in, 669–670 biosphere and, 660; birds and, 507; carbon-oxygen cycle in, 665–667, *666;* cells and, 70–79; changes in, 685–697; and convergent evolution, 197; crustaceans and, 417–418; ecology and, 660; ecosystems as, 660–*661;* and evolution, 190; heredity and, 116; insects and, 432; interactions in, 662–664; isolated, 192–194; levels of organization in, 662; and life, 29–31, 70–79; light and, 81–82, 676; marsupials and, 195–196; nitrogen cycle in, 666–669, *668;* organisms in, 187–188; physical, 662, 663, 673–677; populations in, 190, 661–662; root responses to, 322–323; and speciation, 194–195; water and, 663–665, *664*, 676–677, 718–721
Enzymes, 48; amylase, 368; of bacteria, 227–228; digestive, 57, 568, 571, 576–578; extracellular, 95; and genes, 153, 168; intracellular, 95; lysozymes, 242; in mitochondria, 60; in *Neurospora*, 150–152; and phenylpyruvic idiocy, 168; photosynthesis and, 84; respiratory, 98, 99–100; RNA control of, 58–63
Eocene period, bats in, 525; sea cows in, 529
Epicotyl, of bean seed, 363, 369; corn kernel, 364, 369; in germinating seed, 368, 369
Epidermis, of earthworm, 395; human skin, 596; of leaf, 343; plants, 308; root, 315; sponge, 376; stem, 334; twig, 330
Epididymis, 648
Epiglottis, human, 601
Epinephrine, 643
Epiphytes, 706
Epithelial cells, human, 596
Epithelial tissue, 551, *552*, (Table) 553
Epithelium, of brain, 614
Equator, cellular, 106, 107
Equatorial plate, 106, 110, 112
Equatorial regions, 687
Equilibrium, 615, 624; molecular, 73
Equisetums, *300*, 301
Erepsin, 577
Ergosterol, 47
Erosion, 715–718
Erythrocytes, 582
Erythromycin, 251
Eskimos, 158
Esophagus, of bird, 513; of crayfish, 414; of earthworm, 394; of fish, 466; of grasshopper, 428; human, 574
Estivation, 485, 688
Estrogen, 644, 650
Estuaries, 672–673
Ether, 77; diffusion of, 73
Euglena, 259–*260*, (Table) 261
Euglenoid movement, 260
Eustachian tube, of bird, 517; tube, of frog, 478, 479; human, 622
Evaporation, 565, 665; human skin and, 597; reptile skin and, 489; wind and, 677
Evolution, 504; adaptive radiation and, 195–196; convergent, 197; Darwin and, 185–187, 188; definition, 182; and environment, 190; evidence for, 182–184; Lamarck's

theory of, 184–185, 187–188; migration and, 190–191; mutations and, 187, 188–189, 190–191; natural selection and, 185–187, 188–191; phylogenetic tree and, 406–408; recombination and, 189; speciation and, 193–195; of vertebrates, 453–454
Excretion, 72; alcohol and, 630; in birds, 516–517; cellular, 57; in crayfish, 414; in earthworm, 395; in frog, 481–*482;* in grasshopper, 428; human, 594–597; *see also* Elimination
Exoskeleton, 410, 411–412, 415–416
Exotoxins, 241–242, 244
Experiments, controlled, 8–11
Expiration, 604
Extensors, 562
Extinction, of species, 30, 735
Eyepiece, of microscope, 14
Eyes, of bird, 517; color, 165–166; compound, *429;* of fish, 464, 469; of frog, 478; human, 624–*627, 625, 626;* of land snails, 403; of potato, 335; simple, *429;* of snakes, 493; of tuatara, 492; of turtle, 504
Eyespot, of euglena, 260; in planarian, 387

F_1 generation, 119, 120; of dihybrids, 124–126; of fruit flies, 135
F_2 generation, 119, 120; of dihybrids, 125; of fruit flies, 135
Fallopian tubes, *650,* 651, 654
Family, as Linnaean grouping, 204
Fangs, carnivore, 533; snake, *494,* 499
Farming, contour, 716
Fat bodies, of frog, 485
Fatigue, 607
Fats, *46*–47; as food, 565, 568; lipase and, 578
Fatty acids, 46, 568, 577–578
Fatty liver, 631
Feathers, 508–*509,* 510–511
Feces, human, 579; and tapeworms, 389
Feedback, and endocrine glands, 646
Feet, of birds, 512, *514, 515;* claw, 413; frog, *476,* 477, 478; of starfish, 404–405
Femur, of grasshopper, 427; human, *556, 557,* 560
Fer-de-lance, 498
Fermentation, *100;* bacteria and, 222–223, 228–229; Pasteur's studies of, 23–25, 222–223; sauerkraut and, 233; of silage, 233–234; vinegar and, 233; yeast and, 270
Ferns, 298–301, *299*
Fertility, plant breeding and, 177–178
Fertilization, of fish eggs, 469, 537; of flowers, 357–358; of frog's eggs, 483, 537; of gametes, 109, 112; of human ovum, *649*–650, 651–652; of mammals' eggs, 537; membrane, 651
Fertilizers, algae as, 287
Fetus, human, 653, 656
Fever, 243
Fibers, muscle, *561*–563; nerve, 612, 615, 616; phloem, 308, 331–332; xylem, 308, 332
Fibrils, aster and spindle, 105
Fibrin, 586
Fibrinogen, 581, 586
Fibrous roots, 313–314
Fibrovascular bundles, 334, 346
Filaments, algae, 277, 278; of flower, 352
Filoplumes, 508
Filtration, urine and, 596
Finches, 512
Fingers, of primates, 532, *533*
Fins, 463, 464–465; lobed, 472–473
Fire, forests and, *725*–727, *726*
Fish ladder, *732,* 733
Fish and Wildlife Service, 737
Fisher, R. A., 191
Fishes, 19, *456,* 455–470; blind, 676; conservation of, 732–734; countershading of, 463, *682;* as food, 566; forage, 732; game, 732; stocking of, 734
Fission, 387; in algae, 279, 281; in ameba, 256; and bacterial reproduction, *229*–230; cellular, 103–112; in paramecium, *259;* in spirochetes, 236
Flagella, of bacteria, 225–226, *227;* of collar cells, 377; of euglena, 260; human sperm, 649; of water molds, 268
Flagellates, 694
Flatworms, 386–390
Flax, retting of, 232
Fleming, Alexander, 3
Fleming, Sir, Arthur, 250
Flesh-eating mammals, *530*–531, 677–678
Flexors, 562
Flight, birds and, 506, 507–508, 510–511; mammals and, 525
Floods, 718–720
Florey, Dr. Howard, 250
Flowering plants, 303, 306–311; reproduction in, 352–369
Flowers, 307, 352–358; of pea plants, 117
Flukes, 388–389
Follicle, ovarian, 650–651
Food, (Table) 567; algae as, 287, 288, 289; in blood, 581; cell metabolism and, 94; chains, 678–681; definition, 565; infection, 240; molecules, 57; poisoning, 240; preservation, 234–235, 568–569; pyramids, *679*–680; spoilage, 234; webs, 679; *see also* Nutrition
Foraminifers, 263
Ford, E. B., 191
Forebrain, 535
Forest Service, 725, 726, 729
Forests, areas of in U.S., 723, *724;* coniferous, 700, 701, 702–703; conservation of, 723–731; deciduous, 700, 701, 703; rain, 705–707, *706;* succession in, 695
Formula, chemical, 39
Fossils, bird, 506, *507;* dating, 543–544; of mammals, 522; of mollusks, 399; plant, 304; reptile, 489; vertebrate, 453–454
Four-o'clocks, *126,* 127
Fovea, 626, 627
Foxes, 531
Fractures, bone, 556, 557
Fragmentation, of algae cells, 278
Freezing, of foods, 234
Frogs, 19, 455, *456,* 475–488
Frond, of fern, 300
Frontal lobes, 615–616
Fructose, 44, 45; intestinal fluid and, 578; and nutrition, 568; PGAL and, 89
Fruit, 359–363; of flowering plants, 307; as food, 566; maple, 195
Fruit fly, 134–*136, 137*–141, *140;* mutations in, *149*
Fry, fishes, 732
FSH, 650
Fuel, 94; body, 566; for respiration, 99; *see also,* Nutrition; Photosynthesis
Functions, of living things, 12
Fungi, 265–275
Funk, Dr. Casimir, 569
Fur-bearing animals, 531; destruction of, 737–738
Furrows, erosion and, 716, 717

Galactose, 45; intestinal fluid and, 578; and nutrition, 568
Gallatin National Forest, 695–697
Gallbladder, bird, 516; frog, 479; human, 575, 597
Game, birds, *736*–737; fishes, 732; laws, 661
Gametes, 109; of bread mold, 267; chromosome number in, 110; human, 648–650, 651–652; and law of segregation, 120; mosses, 295–297; planarian, 387; in Punnett square, 122; recombination and, 189; of *Ulothrix,* 283, 284–286
Gametophyte generation, algae, 286; ferns, 300–301; in flow-

ering plants, 359; mosses, 295–297
Gamma globulin, 6–7, 9
Gamma rays, 37
Ganglia, of bivalve mollusks, 401; of earthworms, 396; of grasshopper, 429; of retina, 625; in spinal nerves, 617; sympathetic, 618
Gases, 33; diffusion of, 73; methane, 229; mixture, 40–41
Gastric, caeca, of grasshopper, 428; fluid, 575, 577; glands, 479, 574, 577; protease, 577
Gastritis, 631
Gastrocoel, 653
Gastropods, 402–403
Gastrovascular cavity, of hydra, 380; of medusa, 381
Gastrula, 653
Gavials, 501, *502*
Geckos, 500
Gel phase, 42, *58;* in prophase, 105; in telophase, 107
Gemmules, 377
Gene frequencies, human, 157–159
Gene linkage, 134, 141
Gene pools, 157–159, 195
Genes, 27, 104, 110, 120–124, 648; action of, 144, 146; behavior and, 455–457; and chromosomes, 132–134; and enzymes, 152, 168; human, 144, 146, 155, 163–167; recombination of, 189; Sutton's hypothesis of, 132–133
Genetic code, 142; DNA and, 52, 95, 104; errors in (mutations), 146–149; RNA and, 58
Genetics, breeding and, 170; chromosome number and, 110; definition, 12, 116; diagramming crosses in, 122; human, 155–168; meiosis and, 112; Mendel and, 116–128, 131–132; molds and, 150–153; population, 156–159, 190; sex linkage in, 137–139; *see* also Heredity; Inheritance
Genital pore, in flukes, 388
Genotypes, 120–122; of dihybrids, 125
Genus, as Linnaean grouping, 204; characteristics, 195
Geological timetable, 182, *183*
Geotropism, *323*
Germ, layers, primary, 653, (Table) 655; mutations, 146
Germ Theory of Disease, 238, 239
Germination, bean seed, *367*, 369; corn kernel, *368*, 369; seed, 366–369, *367*, *368*
Germinative layer, human skin, 596
Gestation periods, of mammals, (Table) 537
Giants, 642
Gibbon, 532
Gila monster, 500–501
Gills, 455, 463, 464, 466, *467*–468, 534; arch, 467, 468; cover, 464; in crayfish, 413, 415; in crustacea, 412; filaments, 467; of mollusks, 400, 401; of mushroom, 274; rakers, 467; slits in chordate, 453, 455
Ginkgo tree, 304, *305*
Giraffe, 531–532
Gizzard, bird, 516; earthworms, 394; grasshopper, 428
Glands, endocrine, 639–646, *640*, (Table) 645; gastric, 479, 574, 577; intestinal, 575; mammary, 523, 537; mucous, of frog, 479; pancreas, 643–644; prostate, 648–649; salivary, *572*, 577; tear, 627
Glomerulus, 596
Glottis, of frog, 479, 480; of snake, 495
Glucose, *44*, *45;* intestinal fluid and, 578; light and, 85; liver and, 577; molecules, 62; and nutrition, 568; oxidized in respiration, 99–101; PGAL and, 89; photosynthesis and, 82, 84, 85, 89, 94, 349; and plant respiration, 347–348
Gluten, 569
Glycerin, 568; lipase and, 577; villi and, 579
Glycerol, 46
Glycine, 98
Glycogen, 45; in body, 568, 607; liver and, 577
Gnawing mammals, 525–526
Goat, 531
Goiter, 640
Golden plover, 690, *691*
Golgi, Camillo, 60
Golgi bodies, 57, 60–61, *64*
Gonadotropic hormones, 641
Gonads, 469, 648
Gopher, 525; tortoise, *504*
Gorilla, 532, *546*
Grafting, 177, 336–337
Grana, 61, *82*–83, 84, 85, 87
Grand Canyon, 192
Granules, 84
Grasshopper, 426–430
Grasslands, 700, 703–*704*
Gray matter, 614–615, 616, 617
Gray wolf, 530
Grebe, 513
Green glands, 414
Griffith, Frederick, 143–144
Gross, Dr. Ludwik, 219
Grouse, 518
Growth, of ameba, 256; bacteria, 226–229; cellular, 103; of embryo, 652–655, *654;* of fungi, 274; hormone, 426, 641; of living organisms, 26–29; root, 322–323; of seedling, 368–369; of stems, 326–*328;* of tapeworms, 390
Grub, 424
Grunion, 692, 693
Guanin crystals, of fishes, 463
Guanine, 50, 96, 142
Guard cells, leaf, 343, 346–347, 350
Guinea, pigs, dominant and recessive genes in, 123–124; worm, 390
Gull, *456*
Gullet, of euglena, 260; of frog, 479; of paramecium, 257; of snake, 495
Gymnosperms, 303, *304*–306

Habitats, 672–683
Hairs, root, *315;* in statocyst, 414–415
Half-life, 543
Hammer bone, 622
Haploid chromosome number, 110, 112, 120, 136; human, 648, 649; in mosses, 296; plants, 355, 356, 358; of *Ulothrix*, 284
Haploidy, 189
Hares, 526, 528
Harvestman, 421
Harvey, William, *2*
Hatchery programs, 734
Haversian canals, 557, 560
Hawks, 512, 513, 520, 685
Healing of wounds, 583–586
Hearing, of bird, 517; human, 623–624
Heart, of amphibians, 535; of bird, 455, 517; dorsal, 410; fish, 455, *466*, 534–535; frog, 455, 480–*481;* of grasshopper, 429; of mammals, 455, *534*–535; of reptiles, 535; snake, 496
Heart (human), 587–593, *588*
Heartwood, 330
Heat, body, 565, 566, 597; receptors, 619–620; from respiration, 100; from sun, 660
Heine, Dr. Jacob, 6, 8
Hemiptera, 440
Hemlocks, 305
Hemoglobin, 95, 582, 602, 607, 609
Hemophilia, 139, 163–164, *165*
Hemotoxin, 499
Hen, *518*
Henle's loop, 595
Hepatic portal vein, of frog, 481
Herbaceous stems, 325, 333–336
Herbivores, 426–427, 532, 677
Heredity, and environment, 116; human, 155–168; laws of, 119–128; Mendel's experiments with, 116–119; science of, 3, 116; *see also* Inheritance
Hereford cattle, *178*, 180
Heroin, 634
Heterocysts, 279
Heterogametes, 109; of algae, 278; mosses, 296; of *Oedogonium*, 284

Heterotrophs, 91, 349, 677, 681; euglena as, 260–261
Heterozygous organisms, 125, 126, 127, 135; human, 157–158, 162, 163; and incomplete dominance, 126; in monohybrid crosses, 122–124; mutations and, 147, 188; recombination and, 189; and sex linkage, 137–138
Hexose, 89, 568
Hibernation, 485, 688
Hilum, of bean seed, 362
Hindbrain, 535
Hippopotamus, 532
Histidine, 98
Hive, bee, 437
Holdfast cell, 282, 283
Holstein-Friesian cow, *178*
Homeostasis, 70–71; in leaves, 346
Hominidae, 205
Homoiothermic animals, 674–675
Homologous, chromosomes, 110–112, 141; organs, 182, 413, 427, 434
Homoptera, 440–441
Homozygous organisms, 122–124, 127; gene mutations and, 188–189; human, 157–158, 162, 163; and incomplete dominance, 126–127; in monohybrid crosses, 122–124
Honeybees, 435–438, *436;* pollination and, 356–*357;* winter and, 687
Hooke, Robert, 55
Hookworms, 390, 391–392
Hormones, 95, 639–644; estrogen, 644, 650; FSH, 650; and insect metamorphosis, 426; LH, 651; progesterone, 644, 651; and root growth, 322; and sex-limited traits, 164–165
Hornets, 439
Horns, of gray matter, 616
Horny layer, human skin, 596
Horny outer layer (shell), 401
Horse, 522, 531, 532
Horsetail rushes, *300*, 301
Host, for fungi, 265, 267, 268, 269; of infectious organisms, 241; parasites and, 680; of parasitic bacteria, 227; of sea lamprey, 459–*460*
Housefly, *441*–442, foot, *441*
Hummingbirds, 507, 512; and pollination, 357
Humus, 712, 731
Hybrid, corn, *172*, 173, *174*, *175;* vigor, *172*, 179
Hybridization, 172
Hybrids, 120, 122–*126*, 135; and incomplete dominance, *126*–127, *128*
Hydra, 378–382, *379*
Hydrochloric acid, 574, 577
Hydrogen, acceptor, 87; atom, 35, 38–39; isotopes, *36;* and photosynthesis, 87, 88; and plants respiration, 347–348; and respiration, 99–100
Hydrogenation, 46
Hydrolysis, 46; of starch, 577
Hydrophobia, 246–247
Hydrophytes, 675
Hydrotropism, *323*
Hymenoptera, 435–439
Hyperthyroidism, 639–640
Hypha, of bracket fungi, 274–275; of bread mold, 267, 268; of fungi, 265; of mushroom, 274; of wheat rust, 271
Hypocotyl, of bean seed, 363, 368–369; corn kernel, 364, 366, 368–369
Hypoglycemia, 644
Hypothesis, 9–11
Hypothyroidism, 640

Ichneumon fly, 439
Idiocy, 167–168
Iguanas, 500
Ileum, 575
Image, magnification of, 14–15; resolution of, 14–15
Immunity, 11; acquired, 244; active, 244–245; after virus infections, 219; natural, 244; passive, 244–245
Immunization, 244–249; anthrax, 246; diphtheria, 247–249; polio, 7–8; rabies, 247; smallpox, 245–246
Impulse, nerve, 613, 616–*617*
Inbreeding, *173*, 174
Incisors, human, 573
Incubation, of bird eggs, 518, 519, 520; temperature, of chick embryos, *8*
Indians, 159
Industrial melanism, *192*
Infantile paralysis, 6; *see also* Polio
Infections, phage, *216*–219, *218;* virus, *214*, 215, 219–220; *see also* Diseases
Inflammation, and disease, 243
Infusion, definition, 23; hay, 694–695
Inheritance, of acquired characteristics, 185; chromosome theory of, 131–132; human, 155–168
Inherited characteristics, 116, 131; chromosomes and, 133–134
Insecticides, 445–446, 727
Insectivores, 525
Insects, 410, 411, 423–430, 432–448; birds and, 512, 513; and disease, 235–236, 241, 262–263; forests and, 727–728; frogs and, 476, 477, 478; grassland, 704; as pollinators, 356–357; rain forest, 706; and rickettsiae, 235–236; taiga, 702; tundra, 701; winter and, 687
Insertion, skeletal muscles, 562
Inspiration, breathing and, 604
Instincts, 457
Insulin, 643–644
Integumentary system, vertebrate, 454
Intelligence, in carnivores, 530; inheritance of, 166–167; in twins, 160, 167; quotient, 166
Interbreeding, barriers to, 190–191, 192–193; migration, and, 190–191
Intercellular layer, 57, 63
Interdependence, cellular, 374
Interface, 58
Internode, plant stem, 326
Interphase, 104
Intestines, of earthworms, 394; of fish, 466; of grasshopper, 428; human, 575; of planarians, 387; parasites in, 390, 391–392; protozoans in, 263
Invertebrates, definition, 374–*375;* characteristics, 452; and vertebrates, 452, 453
Iodine, 566; and larva; and salamanders, 475; in thyroid gland, 639–641
Ions, bonds and pairs, 39; most common, 41; and plasma membrane, 71–73, 77; and root absorption, 321
I.Q., 166
Iris, *176;* human eye, 624–625
Iron compounds, 566
Irrigation, 717–*718*, 720
Irritability, 29
Islets of Langerhans, 643
Isogametes, 109; of algae, 278; of *Ulothrix,* 284
Isolation, evolution and, 192–193
Isopods, 418
Isoptera, 439–440
Isotopes, *36*–37; and photosynthesis, 85; radioactive, 56, 64, 543–544
Isthmus, of fish head, 464

Jacobson's organs, 493
Jaguars, 530
Jaundice, 575
Jaws, arthropod, 410; in carnivores, 530; crayfish, 412; grasshopper, 426–427; human, 574; snake, *494*
Jejunum, 575–576
Jellyfish, 377, *380*–381
Jenner, Edward, 2, 5, 213, 245–*246*
Joints, human, *560*–561
Jungle, rain forest and, 706–707
Jurassic period, 454; birds in, 506; toads and frogs and, 475–476; turtles in, 503

Kaibab squirrel, 192, *193*
Kangaroo, 524, *525*
Katydid, 430
Kettlewell, H. B. D., 191–192
Kidneys, bird, 516–517; fish, 466; frog, 479, 481–482; hu-

man, 565, 568, 594–*596*, *595;* of mammals, 534
Killdeer, 520
Kingdoms, as Linnaean grouping, 204
Kingfisher, 513
Knee, jerk, 617; joint, 560
Knees, cypress, 318
Knipling, Dr. Edward, 447–448
Koala bear, 196
Koch, Robert, 2, 238–239
Komodo dragon, 501

Labium, of bee, 437; of butterfly or moth, 433; of grasshopper, 427
Labrum, of grasshopper, 426
Lacewing, *433*, 441
Lactase, 577
Lacteals, 579
Lactic acid, 100; and fatigue, 607; fermentation and, 223, 229; and sauerkraut, 232; and silage, 232
Lactobacillus, 232
Lactogenic hormone, 641
Lactose, 45; intestinal fluid and, 578; and nutrition, 568
Ladybugs, 440
Lagomorphs, 528
Lakes, as ecosystems, 660–*661*, 662–663, 672, 677–680; fish population of, 732; succession in, 695–697, *696*
Lamarck, Jean Baptiste, 184–185, 187–188
Land formations, 677
Landsteiner, Dr. Karl, 6, 8, 160–161
Larva, bilateral, 404; of crayfish, 415; of echinoderms, 404, *405;* of flukes, 388–389; insect, (Table) 426; in insect metamorphosis, 424, 434; of housefly, 441–442; of mosquito, *442;* of Odonata, 440; of queen bee, 436; sea lamprey, 460, 461; trochophore (mollusk), *399*, 400
Larval forms, 407
Larynx, human, 601
Lateral, buds, 325–326, 329; line, of fishes, 465; undulatory movement, 495; ventricles, of brain, 614
Latin, classification and, 199
Latitude, climate and, 700, *701*
Laws of heredity, Mendel's, 119–128
Layering, 336
Layers, of cell wall, 57, 63, *65;* primary germ, 653, (Table) 655
Leaching, 714
Leaf scars, 325, 326
Leaflet, 342, 343
Leakey, Dr. L. S. B., *544*
Leather, tanning, bacteria and, 232
Leaves, 341–350, *342;* as compost, 714–715; flowering plant, 307; node and, 326
Leeches, *396*
Leghorns, 178
Legumes, 668
Lemurs, 532
Lens, human eye, 624, 625; of microscope, 13–14; of snake eyes, 493
Lenticels, 326
Leopard, *456*
Lepidoptera, 433–435
Leucocytes, 243, 582
Leucoplasts, 62
Leukemia, viruses and, 220
LH, 651
Lice, 235
Lichens, 289–*290*, 701
Life, biochemical state of, 3; characteristics of, 25–31; chemical basis of, 33–52; competition for, 186–187, 662; DNA and, 51–52; environment and, 29–31, 70–79; structural basis of, 55–68
Life cycle (history), *Aurelia*, 381, butterflies and moths, 434–435; corn smut, *272*, 273; fern, *299*, 300–301; frog, *484;* moss, 295–297, *296;* *Oedogonium*, 283–284; parasitic worms, 388–*392*, *389;* *Plasmodium*, *262;* *Ulothrix*, 282–283; wheat rust, 271, *272*
Life span, of fruit fly, 135; human, 155; of living organisms, 27–28
Ligaments, *554*, *555*, 560
Light, and bean seedling, 10–11; and environment, 81–82, 676; importance of, 81–82; leaves and, 341, 344–*345;* microscope, 4, 14–15, 56; photosynthesis and, 82–88; rays, 89; reaction of photosynthesis, 86–88, *87;* rhythmic behavior and, 685, 692–693; stem growth and, 328; visible spectrum, 89–90
Lignin, 63
Lille, University of, 222
Limb modifications, in mammals, 533
Lime, 381–382, 412, 426, 674
Lime-producing glands, of birds, 518
Limiting factors, 672–*673*
Linnaeus, Carolus, 199–201, 204
Lions, 530
Lipase, 577
Littoral zone, 707, 708
Liver, alcohol and, 631; bird, 516; fish, 466; frog, 479, 481; human, 568, 575, 577, 581, 597; insulin and, 643
Liverworts, 294, 297, 298
Lizards, 500–*501;* salamanders and, 474
Llama, 190, 531, 532
Loam, 673, 712
Lobes, of human cerebrum, *615*–616; of pituitary gland, 641–642
Lobsters, 410; spiny, *416*
Locker, Joseph D., *8*
Locomotion, anteater, 528; of aquatic mammals, 528; grasshopper, 427; snake, 495; *see also* Movement
Locusts, 430
Loon, 513
Lumbering, 724, 727, 728–730
Lung books, 420
Lungfishes, 472–473
Lungs, bird, 516; frog, 479, 480; human, 597, 601–610, *603;* in lungfish, 472–473; of mammals, 534–535; smoking and, 637; snake, 496
Luteinizing hormone, 651
Lymph, 593–594; and disease 243; nodes, 593; vessels, 579, 593–*594*
Lymphatics, 593–*594*
Lymphocytes, 646
Lynx, 530
Lysogenic cycle, 219; phages, 218, 219
Lysozymes, 242
Lytic cycle, 216, *217*

MacLeod, C. M., 144
McCarthy, M., 144
McIntosh apple, 176
Macronucleus, of paramecium, 258–259
Madison River Canyon, 695–697
Maggots, 19, 20, 424, 441–442
Magnesium, 566
Magnification, of image, 14–15
Maidenhair tree, 304
Malaria, 3, 262–263, 443
Malpighi, Marcello, 2–3
Malpighian tubules, of grasshopper, 428
Maltase, 577
Maltose, *45;* and nutrition, 568
Mammals, 454, 455, 522–538; man and, 542; placental, 195, 196, 197, 524, 537; pouched, 195–*196*, 524
Mammoths, 522, 530
Man, *Australophithecus* and, 544, *548;* Cro-Magnon, 546; and deciduous forest biome, 703; development of, 542–543, 544–549, *548;* and grasslands, 703; *Homo habilis*, 544; *Homo sapiens*, 546–549, *548;* Java, 545; Neanderthal, 545, *548;* and other mammals, 542; Peking, 545; and physical environment, 663; primitive, 543–546; racial types, 548–549; *Zinjanthropus* and, 554, *545*, 547
Manatee, 529–530
Mandibles, of crayfish, 412, 414; of grasshopper, 426

Mantle, of mollusks, 400, 401; cavity, 400, 401
Maples, speciation in, *194*–195
March of Dimes, 5
Marijuana, 634–635
Marine, biome, *707*–708; organisms, 675
Marmosets, 532
Marrow, 557–560
Marsupials, 195–*196*, 524
Mass, 33; selection, 171–172, 174, 178
Mastigophora, 260
Mastodons, 522, *523*, 530
Matrix, of *Nostoc* algae, 279
Matter, 33–34
Maturation region, root, *314*, 315
Maxilla, of bee, 437; of crayfish, 412, 414; of grasshopper, 426
Maxillary teeth, of frog, 478
Maxillipeds, of crayfish, 412, 415
Medin, Dr., 6, 9
Medulla, 6; adrenal, 642, 643; of bird, 517; kidney 595
Medulla oblongata, of fish, 468; of frog, 482; human, 616, 617, 619; of mammals, 536
Medusa, 380–381
Megaspores, 356
Meiosis, *111*–112, 133–134; in *Ascaris*, 131; and crossing over, 141; of megaspore mother cell, 356; of microspore mother cell, 354; in mosses, 296; of *Ulothrix*, 286
Membranes, of brain, 613–614; diffusion through, 74–78; extraembryonic, 654; fertilization, 651; mucous, 242; nictitating, 478, 479; nuclear, 57, 60; periosteum, 557; permeable, 72–73; placenta, 655–656; plasma, 58–60, 71–73, 103, 225; pleural, 602; stomach lining, 575; tympanic, 478, 504; uterus lining, 650, 651–652; vacuolar, 60, 62; web, 478
Mendel, Gregor, 2, 116–128, *117*, 131–133, 134–136
Meninges, 613, 614
Menstruation, 651
Mental disorders, inherited, 167–168
Meristematic, regions, growth from, 327; root, *314*–315; tissue, 308
Mesentery, of frog, 479
Mesoderm, of human embryo, 653; in worms, 386
Mesoglea, 378, 380
Mesophyll, of leaf, 343, 346
Mesophytes, 676
Mesothorax, of grasshopper, 427
Mesozoic era, 306; lobed fins and, 472; reptiles in, 490, 491, 500, 501
Metabolic wastes, of bacteria, 230; in mammals, 533
Metabolism, in birds, 512; of cells, 94–101; rate of human, 607–608; in mammals, 533; thyroid and, 639–641
Metamorphosis, amphibian, 473; frog, 483–485, *484;* insect, 424–426, *425*, 434, 440; peeper, 476
Metaphase, 104, 106, 110
Metathorax, of grasshopper, 427
Methane, 229
Methyl cellulose, 257
Microbiology, 13, 211
Micrographia, 55
Micronucleus, of paramecium, 259
Micropyle, 355, 356, 357; of bean seed, 362
Microscopes, 3, 4–5, *13*–16, 22, 56
Microspore mother cells, 354
Microspores, 355
Midbrain, 535
Middle, ear, of frog, 478; human, 622–624; lamella, 57, 63
Midgets, 642
Midrib, leaf, 341
Migration, 30–31; animal, 688–689; bird, 690–692, *691;* butterfly, *689*–690; and speciation, 194; variations and, 190–191
Mildews, 269
Milk, 566, 569; pasteurization, 234
Milkweed pod, 362
Millepede, 410, *418*–419
Milt, 469
Mimicry, 682
Mindanao Deep, 676
Minerals, in blood, 581; root absorption, 321–322; in soil, 712, 713–714
Mink, 531
Mites, 235, 421
Mitochondria, 57, 60, *63;* respiration and, 98–99, 100–101
Mitosis, 104–107, *105, 106*, 110, 133; in ameba, 256; of human zygote, 652; of megaspores, 356–357; in *Ulothrix* algae, 286
Mixtures, 40–41, solutions and suspensions, 41–42
Moas, 511
Molars, human, 574
Molds, 265–269, *266;* mutations and, 149–152; reproduction, 108, *266*
Molecules, 5, 38, *39;* cell penetration by, 78–79; DNA, 142–143; metabolism and, 94; organic, 44–52; and plasma membrane, 71–73; in solution, 41
Moles, 525
Mollusks, 399–404, *400*
Molting, in birds, 509–510; of caterpillar, 434; in crayfish, 414; of exoskeleton, 412
Monera, 206–207
Mongolian idiocy, 141, 167–168
Mongoloid type, 546–547
Monkey kidney tissue, 6, 7
Monkeys, 532
Monocots, (Table) 308; flowers of, 354; seeds of, 362, (Table) 364; stems, 334, *335*
Monosaccharides, 45, 89; and nutrition, 568
Monotremes, 523
Moose, 531, 532
Morel, *270*, 271
Morgan, Thomas Hunt, *134*–136, 135, 137–139
Morphine, 634
Morphology, 399
Mosquitoes, 441, 442–443; malaria and, 262–263
Mosses, 294–297, *295*, 296, 701
Mother cell, 103–104, 107; megaspore, 355–356; microspore, 354; of yeast, 269–270
Moths, 433–*434*, (Table) 435; peppered, 191–*192;* pollination and, 356
Motion sickness, 624
Motor, neurons, 612–*613;* units, 561
Motor areas, of cerebrum, 614–615
Motor end plate, 613
Mountain lion, *530*
Mountains, climate and, 700, *701*
Mouth, butterfly or moth, 433–434; earthworm, 394; fish, 466, 468; frog, 478–*479*, 480; grasshopper, *426*–427; human, 571, *572–574;* mosquito, 422; roundworm, 391; snake, 493
Mouth cavity, of paramecium, 257
Movement, of air, 677; ameboid, 254; of bird wings, 509, 510, 511; Brownian, 226; cellular, 57; euglenoid, 260; flagella and, 225–226; of food in stem, 338; of paramecium, 256–257; of snake, 495; of water in stems, 337–338
Mucous, feeders, 401; glands, frog stomach, 479; membranes, as barrier to disease, *242*
Mucus, digestion and, 572; in gastric fluid, 575, 577; lining of uterus, 651
Mulch, 297
Mule, 179
Muller, H. J., 134–135, *148*–149
Multicellular organisms, 65; 374–375, 377
Mumps, 572
Muscles, bee, 435–436; bird, 510, 511; in bivalve mollusks,

401; brain areas and, 614–615, 616; earthworm, 394; eye, 625, 627; fish, 465; human, *558, 559,* 561–563, *562;* tissue of, 551, (Table) 553, 561; used in breathing, 604
Mushrooms, *273*–274
Muskrat, 525
Mussels, 402
Mutations, 146–152; bud, 176; evolution and, 187, 188–189, 190–194; and speciation, 194
Mutualism, 680–681
Mycelium, 265; bread mold, 267; mushroom, 273–274
Mycophyta, 265
Myofibrils, 561
Myriapoda, 418
Myxedema, 640
Myxomycophyta, 265

Narcotics, 630, 633–635
Nasal, cavities, of fish, 464; of snake, 493; passages, human, 600, *622*
National forests, 724, 739
National Foundation for Infantile Paralysis, 5, 7
National parks, 739
Natural selection, and insecticides, 445, 727; theory of, 185–187, 188–191
Navel, 656
Neck, of tooth, 574
Nectar, of flowers, 356–357, 433, 437
Necturus, *474*
Needham, John, 22–23
Needles, of conifers, 305
Negative, charges, of electrons, 35; response, root, 322
Negroid type, 547
Nemathelminthes, 390–392
Nematocysts, 378, 379
Nematoda, 390–392
Nephrons, *595*–596
Nerve, net, 380; tissue, 535
Nerves, auditory, 623; of fish, 468; human, 612–617; longitudinal, 387; muscles and, 561; olfactory, 622; optic, 625; skin endings (receptors), *619*–620; tissue, 551, (Table) 553; tranverse, 387
Nervous system, of arthropods, 410; of bird, 517; of bivalve mollusks, 401; of crayfish, 414–415; of earthworms, 395–396; of fish, 468–469; of flukes, 388; of frog, 482; of grasshopper, 429; of mammals, 535–536; of planarians, 387; ventral, 410, 412; vertebrate, 455
Nervous system (human), 612–627, 620; alcohol and, 631; and endocrine glands, 646; muscles and, 561
Neurons, 612–*613,* 614, 617–618
Neuroptera, 441
Neurospora crassa, 150–152
Neurotoxin, 499
Neutrons, 35, 36
New Jersey Agricultural Experiment Station, 251–252
New Zealand, tuataras and, 492
Newt, 474–475
Niche, 672; of hawks, 685
Nitrates, 667, 668
Nitrification, 667
Nitrogen, in DNA, 49; and insectivorous plants, 345; cycle, 667–669, *668;* fixation, 668
Nobel prize, 6, 134, 153, 214
Nocturnal organisms, 685–687
Node, plant stem, 326
Nondisjunction, 139–141, *140,* 146, 189; human, *167*–168
Nonelectrolytes, 41
Nose, human, 600, *622*
Nostrils, of crocodilians, 501; of frog, 478, 479, 480; of snake, 493; of turtle, 504
Notochord, *453*
Nucleic acids, 49–52; in virus core, 214
Nucleolus (i), 57, 58
Nucleoplasm, 58
Nucleotides, DNA, bases in, 51–52, 95–96, 97–*98;* and interphase, 104
Nucleus, atomic, 35; of cell, 48–52, 57–58, *62,* 96; mitosis and, 104–107; of egg and sperm cells, 131; of megaspore, 356; of microspore and megaspore mother cells, 354–355; of paramecium, 258; of somatic cells, 136
Nutrients, organic, 566; *see also* Food
Nutrition, of bacteria, 227–228; cellular, 57, 81–92; human, 565–571
Nutritional relationships, 677–681
Nymph, in insect metamorphosis, 424

Objectives, microscope, 14
Occipital lobes, 614, 625
Oceanographers, 4
Oceans, day-night rhythms in, 685–687; tides, 692–*693;* zones in, *707*–708
Odonata, 440
Oil, on bird feathers, 509; whale, 529; as food, 568
Olduvai Gorge, 544
Olfactory lobes, 468–469, 482, 517, 535, 536
Olfactory nerves, human, *622;* of bird, *517;* of snake, 493
Olympic elk, 688
One-celled organisms, 28
Oocytes, 112
Oogonial cell, 111–112
Oogonium, in *Oedogonium,* 284
Ootid, 112
Open system of blood circulation, 414
Operculum, 464, 468
Opium, 634
Opossum, 522, 524
Opsonins, 244
Optic lobes, 429, 468, 469, 482, 517, 535
Optic nerve, of bird, *517;* human, 625
Optic region, of mammals, 536
Oral, groove, of paramecium, 257; vaccine, polio, 8, 10
Orangutan, 532
Orb weavers, 419
Orders, as Linnaean grouping, 204; of living reptiles, (Table) 491; of mammals, (Table) 526, *527*
Ordovician period, 459
Organ systems, 68
Organelles, 60, 76
Organic, catalyst, 48; compounds, 43–48; matter in soil, 712, 714–715; nutrients, 566
Organs, 66–68; analogous, 413–414; homologous, 413, 427, 434
Origin, skeletal muscles, 562
Origin of Species by Natural Selection, 185
Ornithine, 151–153
Ordovician period, 453
Orthoptera, 426–430
Osmosis, 75–76; and leaf, 347; in root, 320–321
Osmotic pressure, 320–321, 337
Ossification, 556
Osteichthyes, 462
Ostracods, 418
Ostrich, 507, 511, 518
Outbreeding, 172
Oval window, 623
Ovaries, 110, 112; of birds, 517–518; of fish, 469; of flower, 352, 353, 355, 359; of frog, 482; of grasshopper, 429; hormone secretions, 641, 644–646; human, *650–651;* in hydra, 380
Overproduction, 186
Oviduct, of bird, 517–518; of frog, 479, 482
Oviparous snakes, 496
Ovipositors, 430, 437
Ovoviviparous snakes, *496,* 497
Ovulation, 651
Ovules, 353, 358; of bean seed, 362; formation, *355*–358; seeds and, 359
Ovum, 109; human, *649*–650, 651–652; *see also* egg
Owls, 513, 517, 520
Ox, 531, 532
Oxidation, and alcohol in body, 630; in body, 565, 566, 607–608; combustion and, 98, 99–101; in snake, 496; thyroid gland and, 639–640
Oxygen, atom, *35,* 36; and bacteria respiration, 228; and

breathing, 602, 605–607; and carbon-oxygen cycle, 665–667, *666;* debt, 605–*607;* heavy, 85; and life, 676–677; molecules, 38–39; and photosynthesis, 84, 85, 86, 88; and respiration, 99–100; in water, *39*
Oxyhemoglobin, 582
Oxytocin, 642
Owls, *670*, 685
Oysters, 401, 402, 693; starfish and, 405–406

Pain, eye and, 627; receptor, 619–620
Palate, 571–572
Paleozoic era, 277; amphibians in, 473; lobed fins and, 472
Palisade cells, leaf, 343, 344, 346
Palpus, of grasshopper, 426
Pancreas, bird, 516; frog, 479; hormone secretions, 643–644; human, 575–576, 577–578
Pancreatic, duct, 576; fluid, 479, 575–576, 577
Paralysis, 618; due to polio, 6
Paramecium, 256–259, (Table) 261
Parasites, bacteria, 227–228; fungi, 265, 268, 269, 271–273, 274–275; worms, 238, 287–392
Parasitism, 680–681
Parasympathetic nervous system, 619
Parathormone, 641, 646
Parenchyma, 308; cells, of leaf, 343; cells, root, 315; spongy, 343
Parental care, in birds, 519–520, 537; in mammals, 537–538
Parietal eye, 492
Parthenogenesis, 110
Passenger pigeons, 735
Pasteur, Louis, 2, 4, 5, 243; and anthrax vaccine, 245; and bacteriology, *222–223;* and rabies, 213, 246–247; and spontaneous generation, 23–25, *24*
Pasteurization, of milk, 233
Pasturing, forests and, 728
Pathogenic organisms, 238–252
Pearls, 401
Pearly layer (shell), 401
Peas, *119;* Mendel's experiments with, 117–120, *118, 121,* 131, 134
Peat, 297, 712; moss, *297*
Pectin, 63
Pectoral fins, 465
Pedicel, of flower, 352, 353
Pedipalps, of spiders, 420
Pelagic zone, 707
Pelecypoda, *401*
Pelican, 513
Pellicle, 257
Pelvis, human, 560; of kidney, 595, 596
Penguin, *511*, 512
Penicillin, 3, 250, *251*, 268–269
Pepsin, 577
Peptides, 577
Peptones, 577
Perch, *464–465*
Percolation beds, 719, *720*
Perennials, 311, 325; seeds of, 366
Pericardial cavity of fish, 466
Pericardium, 587–588
Pericycle, root, 316
Periodicity, 685–693
Periosteum, 557
Peripheral nervous system, 612, 616
Permian period, amphibians in, 473; reptiles in, 489–490
Personality, in twins, 159–160
Perspiration, 565
Pests, insect, control of, 443–448
Petals, of flower, 352, 354
Petiole, leaf, 341, 344, 346, *347*
PGA in photosynthesis, 88–89
PGAL, 91, 94, 349; in photosynthesis, 88–89
Phaeophyta, 287
Phages, *216*–219, *217*
Phagocytic cells, 243, 244
Pharynx, of earthworm, 394; of fish, 466, 468; of flukes, 388; human, 572, 600; of planarians, 387
Phenotypes, 191; of dihybrids, 126; in monohybrid crosses, 122–124
Phenylalanine, 168
Phenylpyruvic idiocy, 168
Phenylthiocarbamide, 157–158
Phipps, James, 245, *246*
Phloem, 308; bark, 331–332; fibers, 332; parenchyma, 332; root, 316, 317; stem, 334
Phosphates, in DNA, 50, 51; and respiration, 100–101; units, 142
Phosphoglyceraldehyde, 88
Phosphoglyceric acid, 88
Phosphorus, in body, 566
Photo phase, 86–88, *87*
Photolysis, 86
Photoreceptors, 625
Photosensitivity, 387
Photosynthesis, 82–*91*, 94, 663, 666, 667; in algae, 277, 280, 282, 288, 289; in euglena, 260; leaves and, 307, 341, 346–347, 348–349; and plant respiration, 348–349, (Table) 348
Phototropism, 328, 344, 387
Phycocyanin, 279
Phycomycetes, 266; bread mold, 266–268, *267*
Phyla, animal, 374–376; as Linnaean grouping, 204
Phylogenetic tree, 406–*408*
Physalia, 382
Physical change, of matter, 33
Physiology, definition, 12
Phytoplankton, 677
Pia mater, 613
Pig, 531, 532
Pigment granules, of fishes, 463
Pigments, 83, 84, 95; in fungi, 265; in green algae, 280; in leaves, 345–346; vacuolar, 62–63
Pikas, 526, 528
Pillbugs, 418
Pineal body, 646
Pineapples, 699
Pines, 305; products of, 730
Pinocytosis, *78–79*
Pinworm, 390
Pioneers, bacteria as, 694
Pistil, of flower, 352, 354, 355, 356, 357; of pea plants, 117
Pit vipers, 493, 498–500
Pitcher plant, 345
Pith, plant, 308; rays, 330; root, 316; stem, 329, 332
Pits, tracheid, 332
PKU, 168
Placenta, 524, 655–656
Placental mammals, 195, 196, 197, 524
Planarians, *386*–387
Plankton, 672, 707–708
Plant eaters, 532
Plants, breeding of, 170–178; dormant, 674; flowering, 303, 307–311; 352–369; herbaceous, 311; insectivorous, 345; reproduction in, 352–369; respiration in, 347–348; seed, 303–311; woody, 311
Planula (e), 381
Plaques, 216
Plasma, blood, 565, 581–582, 587
Plasma membrane, 57, 58–60, 103; of bacteria, 225; diffusion through, 75–78; penetration, 71–73, 75–78, (Table) 72; structure, 71, 78–79
Plasmodium, 262–263, 443
Plasmolysis, 76–77
Plastids, 57, 61–62
Plastron, turtle shell, 504
Platelets, 582, 583
Platyhelminthes, 386–390
Pleistocene era, bears in, 531
Pleural membrane, 602
Plumage, bird, 164
Plymouth Rock, 178
Pneumococcus, 224; transformation in, 143–144, *145*
Pneumonia organisms, 144, *145*, 224
Pod fruits, 360
Poison, of Gila monster, 500–501; insecticides, 445–446; sea lampreys and, 461; snake, 494, 499
Polar, bodies (meiosis), 112; nucleus, ovule, 356, 358; regions, 687, 700, 701

Polio, 5–8, 9, 10, 11; vaccine, 7–8
Pollen, of pea plants, 117; formation, 354–355; sacs, 354; tube, 357
Pollination, 356–357, 443; breeding and, 173, 174; of pea plants, 117
Pollution, *733,* 734
Polyploidy, 176–177, 189
Polyps, coelenterate, 380, 381; coral, 318–382
Polysaccharides, 45; and nutrition, 568
Ponds, farm, 734; succession in, *694,* 695–697, *696*
Pons, 616
Popper, Dr. Erwin, 6, 8
Poppies, opium and, 634
Populations, 157–159, 190, 661–662
Pore, genital, 388; incurrent and excurrent, 376
Porifera, 376
Pork, trichinosis and, 392
Porpoises, 528, *529*
Portal circulation, 593
Portuguese man-of-war, 378, 382
Posterior, horns, 616–617; lobe, pituitary gland, 642
Postulates, Koch's 239
Posture, 542
Potassium-argon dating method, 544
Potassium compounds, 566
Potatoes, 335; Burbank, 170, 171, 173
Pouched mammals, 195–*196,* 524
Poultry, breeding of, *177,* 178
Prairie dog, 525
Praying mantis, *430*
Precipitation, 665
Precipitins, 244
Predators, 192; crocodilians, 501; definition, 670; and fish eggs, 537; sea lampreys, 459–461; sharks, *456, 461*–462; turtles, 503
Premolars, 574
Pressure, diastolic, 591; diffusion, 74, 75–76, 78; in middle ear, 622–623; osmotic, 320–321, 337; root, 320–321, 337; systolic, 591; turgor, 75–77, 321
Pressure receptors, 619–620
Primary, germ layers, 653, (Table) 655; oocycte, 112; quill feathers, 510–511; root, 313; spermatocyte, 112; wall, 57, 63
Primates, 202, 532, *533;* man, 542, 543
Primroses, evening, 187
Prismatic layer (shell) 401
Proboscideans, 530
Proboscis, of butterfly or moth, 433
Producers, food, 677
Progesterone, 644, 651
Proglottids, 389–390
Prontosil, 249
Prop roots, 318
Propagation, by stems, 336–337; vegetative, 146, 173
Prophase, 104, 105, 106, 110; of meiosis, 112
Prostomium, 393–394
Protection, animal, 681–683
Protein filaments, 561
Protein synthesis, *97,* 142; cell growth and, 103
Proteins, *47*–49; antibodies, 244; antigens, 243–244; in chromosomes, 49; erepsin and, 578; as food, 565, 568–569; functions and organization, 95; and nitrogen cycle, 667; pepsin and, 577; peptides and, 577; ribosomes and, 95–98; synthesis, 94–98; in trees, 728
Proteoses, 577
Proterozoic rock, 277
Prothallium, fern, 300
Prothorax, of grasshopper, 427
Prothrombin, 583, 586
Protista, 207, 223, 235, 254
Protococcus, *280*–281
Protonema, mosses, 296
Protonephridia, 407
Protonephron, 407
Protons, 35, 36, 37
Protoplasm, 42, 55; characteristics of, 25–26
Protozoans, 235, 238, 254–263, *255,* 374, 376, 439–440; cellular division, 107–108
Pruning, 337
Pseudocoel, 408
Pseudopodia, 254, 255
Ptarmigan, 509
PTC, 157–158
Pterodactyls, 506
Ptyalin, 576
Puberty, 644–646
Public Health Service, 636
Puffballs, 275
Pulmocutaneous arches, of frog, 480–481
Pulmonary, artery, 589, 591, 593, 602, *603;* circulation, 593; veins, *481,* 589, 593, 602, 603
Pulp cavity, 574
Pulpwood, 729
Pulse, human, 591
Puma, 200, 530
Punnett square, 122, *125*
Pupa, in insect metamorphosis, 424, 434
Pupil, human eye, 624, 625, 626; snake eye, 493
Purines, 50–51, 104, 105
Pus, 243; white corpuscles and, 583
Pygmy, 159
Pyloric caeca, of fish, 466
Pyloric valve, 479, 575, 577
Pylorus, of frog, 479
Pyramids, food, *679–680;* kidney, 595
Pyrenoids, of *Oedogonium,* 283; of *Spirogyra,* 281–282
Pyrimidines, 50–51, 104, 105
Pyrrophyta, 287
Pyruvic acid, 99–100, 607; fermentation and, 229

Q fever, 235
Quadrate bone, 494
Quail, 518
Quarantine, insect, 443–445
Queen Victoria, hemophilia and, 164–*165*
Quill, of feather, 509

Rabbits, 526, 528, *529*
Rabies, 213; Pasteur and, 246–247
Raccoon, 531
Races, 205, 546–549; blood types, (Table) 163
Rachis, of feather, 509
Radiation, adaptive, 195–197; and food preservation, 234; of isotopes, 36–37; medical use, *37;* and mutations, 148–150, 151–153; from sun, 660
Radicles, 363, 364
Radioactive iodine, 37, 640
Radioautography, 64–65
Radiolarians, 263, 385
Radula, 403
Rainfall, 718–721
Rays, fishers, 462; light, 15; pith, 330; of starfish, 404–405
RDP, in photosynthesis, 88, 89
Reactions, nervous, *617,* 618–619
Receptacle, of flower, 352, 353
Receptors, 387; of crayfish, 414; human skin, *619,* 620
Recessive characteristics, 120, 122, 123–124; and nondisjunction, 139–141
Recombination, 190; and evolution, 189
Rectum, 428, 576, 579
Red corpuscles, 95, 560, 566, 582, 586–587, 591; malaria and, 263
Red-green color vision, 162–*163, 164*
Red Sea, 279
Red spores, 271
Redi, Francesco, 20–21
Reduction division, *111*–112; 131–132; and law of segregation, 120, 122
Redwoods, 305
Reefs, coral, *382*
Reflex actions, 617–618; iris, 625
Reforestation, 728–729
Refrigeration, of foods, 234
Regeneration, in amphibians, 485; in crayfish, 416; of pla-

narians, 387, *388;* of starfish, 406
Reindeer moss, 290
Remoras, 681
Renal, arteries, of frog, 481; circulation, 593, 595, 596; veins, of frog, 481
Replication, 51–52, 105, 142; in meiosis, 112
Reproduction, 29; of algae, 278, 279, 280, *281;* 282–283, *284–286*; in ameba, 256; asexual, 107–109, 261, 265, 275, 648; in *Aurelia,* 381; of bacteria, *229*–230, 231; in birds, 517–520, *518, 519;* cellular, 57, 103–112; in crayfish, 415; DNA, 52; in earthworm, *395*–396; in euglena, 261; in ferns, 298–301; in fish, 469–470; in flowering plants, 352–369; of flukes, 389; in frog, 482–483; fungi, 265, 275; in grasshopper, 429–430; in housefly, 441–442, (Table) 442; in hydra, 380; in mammals, 536–537; in mosquitoes, 442; in mosses, 295–297; in paramecium, 258–*259;* of planarians, 387; roots and, 320; of roundworms, 391–392; in seed plants, 117; sexual, 109–112, 131, 231, 265, 267–268, 648; in snakes, 496–497; in spiders, 420; in sponges, 376–377; in spore-forming protozoans, 261–262; in tapeworms, 389–390; vegetative, *108*; of viruses, 214; yeasts, 269–270
Reproduction (human), 648–656
Reproductive system, vertebrate, 455
Reptiles, 489–504; birds and, 506
Reservoir, of euglena, 260
Residual air, 605
Resolution, of image, 14–15
Respiration, algae and, 277, 287; anaerobic, 100, 228, 229, 270, 607; artificial, 605, *606*; in bacteria, 228–229; in birds, 516; cellular, 57, 98–101; in crayfish, 415; in Crustacea, 412; in earthworms, 395; in fish, 467–468; in flowering plants, 307; forms of, 99–100; in frog, 480; fuel for, 99; in grasshopper, 427–428; human, 600–610; in mammals, 534–535; in paramecium, 258; phosphate groups and, 100–101; comparison with photosynthesis, 348–349, (Table) 348; plant, 347–349; in spiders, 420
Response, cellular, 57; of living organisms, 29–31; of roots, 322–323; of vertebrates, 455–457
Reticuloendothelial system, 243
Retina, 625–626
Retting of flax, bacteria and, 232
Rh factor, 162, 587
Rheas, 511
Rhesus monkey, 162, 587
Rhinoceros, 532
Rhizoids, 267; moss, 294–297
Rhizomes, 334–335; of tree ferns, 299
Rhizopus, 266–268
Rhodophyta, 287
Rhynchocephalia, 491–*492*
Rhythms, 685; annual, 693; daily, 685–687; lunar, 685, 692–693; seasonal, 687–692; tidal, 692–693
Riboflavin, 270
Ribonucleic acid, 51, 52; *see also* RNA
Ribose, 51
Ribosomes, 57, 60, 96, 143; protein synthesis and, *95*–98
Ribs, human, 560; and breathing, 604; of snake, 495, 496
Ricketts, Dr. Howard T., 234
Rickettsiae, 234–*235*, 238
Rill erosion, 715
Ring canal, of starfish, 405
Ringworm fungi, 275
RNA, 51, 52, 57, 566; bases in, 96; control of cellular enzymes, 58; formation of, 142; messenger, 96, 142, 144; phage, 216, 219; ribosomes and, 60, 96; transfer, 97–98; in virus core, 214
Roach, 430
Roan offspring, 127
Robins, 513, 519
Robbins, Dr. Frederick C., 6
Rockefeller Institute for Medical Research, 28, 49, 144
Rocky Mountain spotted fever, 235–236
Rodents, 525–526, 528, *670*
Rods, 625–627
Roosevelt, Franklin D., 5
Roosevelt, Theodore, 724
Roots, 313–323; of flowering plant, 307; fungi and, 275; pressure, 320–321, 337; of tooth, 574; of tree ferns, 299
Roquefort cheese, 268
Roses, 176
Rosin, 730
Rostrum, of crustacea, 412
Rotation, of crops, 714
Roughage, 568
Roundworms, 390–392
Royal jelly, 436
Rumen, of ungulates, 532
Ruminants, 532
Rust fungi, 271–273

Sabin, Dr. Albert, 8
Sabin oral vaccine, 10
Sac fungi, 266
Salamanders, *456*, 474–*475;* lizards and, 474
Salientia, 473
Saliva, 572, 573, 577
Salivary amylase, 576
Salivary glands, of grasshopper, 428; human, *572*, 577
Salk, Dr. Jonas E., *7;* test, 10; vaccine, 7–8, 9
Salmon, 193, 457
Salt, table, 41; *see* Sodium Chloride; curing, of foods, 234; as food, 566
Salvarsan, 249
Samaras, 195
Sampling, human genetics and, 157–159
Sand, 673; dollar, 404
Sandworm, *393*
Sap, 338
Sapwood, 329–330
Sarcode, 55
Sarcodina, 254
Sauerkraut, bacteria, 232
Savannah, *704*
Scabs, 586
Saprophytes, 227, 681; fungi, 265, 268, 269, 271–273, 274–275
Scales, birds, 507; bud, 325; of butterfly or moth, 433; of conifers, 305; fish, 463; snakes, 493
Scallops, 402
Scarlet fever, 228
Scavengers, 401–416, *678;* insects, 440, 441, 443; worms, 387
Schizomycophyta, 223
Schleiden, Matthias, 55
Schwann, Theodor, 55
Science, of classification, 199; development of, 2–5; interrelations, 3–4; limitations of, 5; pure and applied, 12
Scientific methods, 3, 8–12
Scion, 336, *337*
Sclerotic layer, 624, 625
Scorpions, *421*
Scotch broom, 699
Screwworm fly, *446*, 447–448
Scrotum, human, 648
Scutes, 493, 495
Sea, cow, 529–530; cucumber, 405, 406; fans, 378; lamprey, 453, *456*, 459–461, *460;* lions, 531; snakes, 498; squirts, 453; turtles, 503; urchin, 404, *405*, 406; water, 90
Sea anemones, *378;* and radial symmetry, *385*
Seals, 531; migration of, 688–689
Seasonal rhythms, 687–692; migrations and, 688–692
Secondary, oocyte, 112; phloem, *317;* quill feathers, 510–511; roots, *313;* sex characteristics, 644–646; spermatocytes, 112; thickening, root, 316–317; wall, 57, 63; xylem, *317*

Secretions, acid in stomach, 242; bile, 576, 577; cellular, 57; digestive enzymes, 571; of ductless glands, 639, 646, (Table) 645; in gastric glands, 575, 577; mucus, 573; royal jelly, 436; of snail, 403; sweat, 565, 597; synovial fluid, 561
Sedges, 362
Sedums, 345
Seedling, growth, 367–369; timber, 729
Seeds, 359–368; of angiosperms, 303, 304, 306, 307; birds and, 512, 513; of conifers, 305; of gymnosperm, 303, 304
Segmented, body of arthropods, 410, 412; worms, 393–394, 400
Segregation, abnormal, 139–141, *140;* law of, 120, *121,* 122, 133; and sex linkage, 138
Self-pollination, 356; and inbreeding, 173, *174;* of pea plants, 117, 119
Semen, 649
Semicircular canals, 623, *624*
Semilunar valves, 589, 590
Seminal receptacles, of earthworm, 396; of grasshopper, 429; of spiders, 420
Seminal vesicles, of earthworm, 396; of frog, 482; human, 648–649
Seminiferous tubules, 648
Semitropical region, 700, 702–703
Sensations, of fish, 469; skin, 619–621
Sense organs, of bird, 517; of grasshopper, 429; human, 619–627; of insects, 432; in primates, 532
Sensitivity, in ameba, 256; in paramecium, 258
Sensory, areas, of cerebrum, 614–615; nerves, 621; neurons, 612, 613, 617
Sepals, of flower, 352
Septum, 588, 600
Serum, definition, 7, 249; albumin, 581; globulin, 581
Sessile, 376
Setae, 394
Sewage, insects and, 447
Sex, chromosomes, *136*–137, 138–139, 140–141, 149–150; determination, 136–137, (Table) 137; hormones, 641, 644–646; linkage, 137–139; *138,* 162–164
Sex-influenced traits, 164
Sex-limited traits, 164–165
Sharks, *456, 461*–462, 681
Shasta daisy, 170, 174
Sheath, bacteria, 224
Sheep, 531, 532
Sheep-liver fluke, 388–*389*
Sheet erosion, *715*
Shellac, 440, 443
Shellfish, 399
Shells, of bird eggs, 518; of bivalve mollusks, *400,* 401, 402; cephalopods, 404; diatoms, 287; of electrons, 38; gastropods, 402–403; of reptile egg, 489; turtle, 503, 504; of virus, 214
Shelterbelts, *717*
Shields, turtle shell, 504
Shock, 586–587
Shortenings, 568
Shorthorn cattle, *178,* 179
Shoulder, of bird, 510
Shrews, 525
Shrimps, 416–417
Side winding, 495
Sieve, plate, of starfish, 405; tubes, 308, 331
Sight, human, 625–627, *626;* in primates, 532
Sigmoid colon, 576
Silage, bacteria and, 232–233
Silk scar, of corn kernel, 364
Silt, 673
Silurian period, 277
Simple, eye, of grasshopper, *429*
Sinoatrial node, 563
Sinus venosus, 466, 481
Siphons, in mollusks, 400, 401
Sirenians, 529, 530
Skate, *456,* 462
Skeletal, muscles, 562; system, vertebrate, 464
Skeletons, of arthropods (exoskeleton), 410, 411–412; bony, 462; cartilage, 453, 454, 455, 461; coral, 381–382; crayfish, 415–416; endoskeleton, 452, 454; human, 552, *554, 555,* 556; starfish, 405; vertebrate, 452, 453, 454
Skin, as barrier to disease, 241, 242; color, 165–166; frog, 477; and frog respiration, 480; human, 596–*597;* reptiles, 489; respiration and, 535; sensations, 619–621
Skinks, 500
S-l valves, 589
Sleeping, pills, 635; sickness, 263, 441, 443
Slime, body of fish, 463; layer, of bacterial cells, 224; molds, 265; ring, of earthworm, 396
Sloths, 528
Slugs, 403
Smallpox, 2, 5, 213; vaccination, 245–*246*
Smell, *621,* 622; in fish, 469; in primates, 532
Smith, Dr. J. L. B., 472
Smoking, 635–637, *636;* and forest fires, 725, 726, 727
Smooth muscle, 561, *562,* 575
Smuts, 273
Snails, 399, *402,* 403; and fluke larvae, 388–389
Snakes, *456,* 492–500
Social insects, 432, 435–439
Sodium chloride, 39, *41,* 566; ionization in water solution (equation) 41
Soil, algae and, 287; bacteria, 231–233; characteristics of, 673–674; composition of, 712–713; conservation, 714–718; flora, 712; forests and, 731; ground water and, 665; organisms, streptomycin and, 251; roots and, 314, 321, 323
Soil Conservation Service, 718
Sol phase, 42, *58;* in prophase, 105; in telophase, 107
Solar plexus, 618
Solids, 33; diffusion of, 73–74
Solute, 41, 42; concentration, active transport and, 78
Solutions, 41–42; and plasma membrane, 71–72, 77; saturated, 41
Solvents, 41, 42; chlorophylls removed by, 84; and penetration of plasma membrane, 77
Somatotropic hormone, 641, 642
Song box, 516
Sori, fern, 299
Sound, ear and, 623, 624
Sowbugs, 418
Space flights, algae and, 289; and respiration, 610
Spallanzani, Lazzaro, *22–23*
Spanish moss, *704*
Sparrow, 519
Spawning, of fish, 469–470; of sea lamprey, 460
Specialization, cellular, 65–66, 71, 374, 394; in crustacea, 412–413; in insect, 423–424, 432; in mammals, 533, 535; of protozoans, (Table) 261
Speciation, 194–195
Species, characteristics, 116; classification and, 199, 200, 201, 204–205, 207; climax, 695, 701; definition, of, 207; development of, 193–195; as Linnaean grouping, 204; preservation, 457
Spectrum, visible, 89
Speech, tongue and, 574
Sperm, 109, 110, 112, 131; bee, 437; bird, 517, 518; crayfish, 415; earthworm, 396; fern, 299–301; of fish, 469, 470, 537; of frog, 482, 483; human, *132,* 648–650, *649,* 651; mosses, 295–297; of *Oedogonium,* 284; of pea plants, 117, 120
Sperm nuclei, of flower, 357
Spermatids, 112
Spermatocytes, 112
Sphagnum, *297*

Spicules, 376, 377
Spiders, 410, *419*–421, *420*
Spinal bulb, 6
Spinal cord, 6, 453; of bird, 517; of fish, 468; of frog, 482; human, 614, 616, *617;* of mammals, 536
Spinal nerves, of frog, 482; human, 616–617; of mammals, 536
Spindle fibrils, 105, 107
Spine, 453; of dorsal fin, 465; of snake, 495
Spinnerets, of spiders, 420
Spiracles, of grasshopper, 428
Spirochetes, 235, 238
Sponges, *375*–377; reproduction, 108, 377
Spongin, 376–377
Spongy cells, leaf, 343, 344, 346
Spontaneous generation, definition, 19; Redi's experiment, 20–*21;* Spallanzani's experiments, *22*–23
Sporangia, fern, 299
Sporangiophore, 267
Sporangium, of bread mold, 267–268
Spore formation, bacterial, *230*–231
Spore-forming protozoans, 261–263
Spore production, 108, *109*
Spores, of algae, 278, 284, 286; fern, 299–300; of fungi, 265, 270–275; mosses, 295–297
Sporophyte generation, algae, 284–285; ferns, 299–301; flowering plants, 359; mosses, 295–297; seed plants, 303
Sporozoa, 261
Sport, rose, 176
Sprouting of seeds, 366–369, *367, 368*
Spruces, 305
Squid, *403*, 404
Squirrels, 525; isolation and, 192, *193*
Stalk, of flower, 352, 353; mosses, 295–297
Stamen, of flower, 352, 354, 357; of pea plants, 117
Stanley, Dr. Wendell, 213–214
Staphylococcus, 216, 224, 250
Starch, 45–*46*, 72, amylase and, 578; in bean seed, 362; in corn kernel, 364; in germinating seed, 368; molecule, 62; and nutrition, 568; ptyalin and, 576
Starfish, 404–*406*
Statocyst, of crayfish, 414–415
Steady state, 70
Stems, 325–338; brain, 616; of fern, 300; of flowering plants, 307; of tree ferns, 298
Sterility, of mule, 179; plant breeding and, 178
Sterilization, and insect control, 447–448
Stickleback, 469, *470*
Stigma, of flower, 352, 356, 357
Stimulus, 29–30, 455, 457, *617*, 619–620
Sting, of bee, 436, 437; ray, *462*
Stingers, of scorpion, 421
Stipe, of mushroom, 274
Stirrup bone, 622
Stock, grafting on, 336, *337*
Stocking, of fish, 734
Stolons, 267
Stomach, acid as barrier to disease, 242; of bird, 516; of fish, 466; of frog, 479; of grasshopper, 428; human, *574–575*; lining, inflammation, 631; poisons (insecticides), 445; of snake, 495; of ungulates, 532
Stomates, leaf, 343–*344*, 346, 350
Streaming, of cell protoplasm, 58, 348
Streptococcus, 224, 240, 241
Streptomycin, 251
Strip, cropping, 716; cutting, 727
Structural, proteins, 95; similarities, classification and, 199, 200, 201, 204
Sturtevant, A. H., 134
Style, of flower, 352, 353, 357
Subarachnoid space, 614
Subclavian veins, 593–594
Subsoil, 665, 712
Succession, 694–*696*, 697
Sucker, of flukes, 388; of leeches, 396
Suckling instinct, 457
Sucrase, 577
Sucrose, 45, 89; intestinal fluid and, 578; and nutrition, 568
Suffocation, tissue, 609
Sugar units, 142
Sugars, *44*–46, *45*, 88, 89; deoxyribose, 49; in germinating seed, 368; insulin and, 643–644; maple, 730–731; and nutrition, 568
Sulfa drugs, 250
Sulfanilamide, 249
Sundew plant, 343
Sunfish, 469, *470*
Superior vena cava, 589, 591, 593
Supplemental air, 605
Suprarenals, 642–643
Survival of the fittest, 187, 190
Suspension, 41–42
Sustained yield, of forest, 727
Sutton, Walter S., 132–134, *133*
Swallowing, 573; by snakes, 494–495
Swarming, of bees, 436
Sweat, 565, 597
Sweepstakes dispersal, 191
Swimmerets, 413, 415
Symbiosis, *290*, 680–681
Symbol, of elements, 34
Symmetry, *385*–387
Sympathetic nervous system, 618–619
Synapse, 612
Synapsis, 112
Synergids, 356
Syngamy, 109
Synovial fluid, 561
Synthesis, of carbohydrates, *see* Photosynthesis; cellular, 57; protein, 94–98, 143
Synthetic, phase, photosynthesis, 88–89; vitamins, 569
Syphilis, 3, 235; cure, 249
Systemic circulation, 593
Systems, of earthworms, 394; human, 551; organs and, 68
Systole, 590

Tadpoles, 455, 476, 483–485; toad, 476
Taiga, 702
Tail, of fishes, 463, 464–465; of tadpole, 483, 485
Tanning, 232, 731
Tapeworms, 389–*390*
Tapir, 532
Taproots, 313
Tarantula, 420
Tarsus, of grasshopper, 427
Taste, buds, 373, 620; as inherited characteristic, 157–158; sense of, *620*, 622
Tatum, Edward L., 150, *151*–153
Taxonomy, 12, 199
Tears, as barrier to disease, 242
Technical method, 11–12
Teeth, in carnivores, 530, 533; of fishes, 464; human, *574;* in rodents and rodent-like mammals, 526, 528; of snake, 493, *494;* in ungulates, 532; in walruses, 531
Teleostomi, 462
Teliospores, 271
Telophase, 104, 107
Telson, of crayfish, 413
Temperate region, 700, 703
Temperature, and bacterial growth, 226; of cold-blooded animals, 485; diffusion and, 74; and environment, 674–675; fungi and, 265–266; in mammals, 533; and mutations, 148; and oxidation, 98; and photosynthesis, *90;* rise in body, 243; and seed germination, 367
Templates, 96, 97–98
Tendons, 562
Tendrils, 345
Tentacles, of hydra, 378, 380; of snail, 403
Termites, 263, *435*, 439–440, 681
Terracing, 716
Terramycin, 251
Terrapins, 502–503
Tertiary period, aquatic mammals in, 528; armadillos in,

525; carnivores in, 530; snakes in, 492
Testa, of bean seed, 362
Testes, 10; of bird, 517; of fish, 469; of frog, 482; of grasshopper, 429; hormone secretions, 641, 644–646; human, 648; in hydra, 380
Testosterone, 644
Tetanus, 228, 241–242; spores, 231
Tetracycline, 252
Tetrad, 112, 141, 355; bacteria, 224
Tetraploid chromosome number, 112; in plants, 177, 178
Thallophyta, 223
Thiouracil, 640
Thoracic cavity, human, 552
Throat, of frog, 479; of snake, *494; see also* Pharynx
Thorax, of crustacea, 412; of insects, 423
Thorns, 345
Thrombin, 583–586
Thrombocytes, 582
Thromboplastin, 583, 586
Thrush, 275
Thumb, opposed, 542
Thymine, 50, 51, 96, 142
Thymus, 646
Thyroid, deficiency, and larval salamanders, 475; extract, 639, 640; gland, 639–*641*
Thyrotropic hormone, 641
Thyroxine, 639
Tibia, of grasshopper, 427
Ticks, 235, 421
Tidal air, 604, 605
Tigers, 530
Timber, 305, 329, 724, 727, 729; types of, (Table) 730
Tissue, fluid, 581, 591, 593–594; suffocation, 609
Tissues, 65–66, *67;* damage to, 107, 637; of earthworms, 394; of flowering plants, 307–310; human, 551, (Table) 553; leaf, *343;* in mammals, 533; monkey kidney, and polio research, 6, 7; nerve, 535; root, 315–*317*, *316*, (Table) 318; vascular, 294; of woody stem, 330–333, (Table) 333
Toads, 475–476
"Toadstool," 274
Tobacco, 630, 635–637; bacteria and, 233; mosaic virus, 213, 214, 215
Toes, of primates, 532, *533;* of ungulates, 532
Tolerance, 672–673
Tone, muscle, 563, 615
Tongue, of bee, 437; frog, 476, *478;* human, 572–573; rolling, 157, 158; of snake, 493; taste and, 620
Tonsils, 593
Tools, man and, 542, 543
Topography, 677; climate and, 700–*701*
Topsoil, 665, 712–713
Tortoises, 502, 503, *504*
Touch-me-not, 361
Tourniquets, and snakebite, 500
Toxins, antitoxins and, 244, 248–249; diphtheria, 247–249; endotoxins, 242; exotoxins, 241–242
Toxoids, 249
TPN, in photosynthesis, 87
$TPNH_2$, 87, 88
Tracer elements, 37, 56
Trachea, of bird, 516; of frog, 480; of grasshopper, 428; human, 600–601, 603; of insects, 412, 420, 423; of snake, 494–495
Tracheids, plant, 308; stem, 332
Tracheophyta, 294, 298, 303
Traits, of garden peas, 117–*118;* genetic sampling of, 157–159; sex-influenced, 164; sex-limited, 164–165
Transformation, in pneumococcus, 143–144, *145*
Transformers, 678
Translocation, 189, 338, 349
Transpiration, of flowering plant, 307; 349–*350;* pull, 338
Transport, blood as medium of, 583, (Table) 586, 593; body systems, 581–598; passive and active, 72–73, 77–78
Transverse, colon, human, 576; fission, of spirochetes, 235; nerves, 387
Tree Farm Program, 727, 729
Tree, frogs, 476; line, 700
Trees, bracket fungi on, 274–275; branching, 328–329; conifers, 304–306, *305,* (Table) 306; succession and, 695; timber, (Table), 730; as windbreakers, *717; see also* Forests, Woody plants, Woody stems
Trematoda, 386, 388–389
Trench fever, 235
Trepang, 406
Triassic period, amphibians in, 473
Triceps, *562*, 563
Trichina worm, 390, 392
Trichinosis, 392
Trichocysts, 258
Triose phosphate, 88
Triple fusion, 358
Triplets, base, 96–98, 142
Triploid chromosome number, 358
Tritium, *36*
Trochanter, of grasshopper, 427
Trochophore larva, *399*, 400
Tropical, forest, 700, 701, 705–*706;* region, 700
Tropisms, root, 322–323
Trunk, of fishes, 463, 464–465
Trunk-nosed mammals, 530
Trypsin, 577–578
Tsetse fly, 263, 441
Tuatara, 491–*492*
Tube feet, of starfish, 404–405
Tube nucleus, 355, 357
Tuber, of potato, 335
Tuberculosis, 166, 228, *240;* streptomycin and, 251; tissue destruction by, 241
Tubule, from Bowman's capsules, 595, 596
Tundra, 701, *702*
Tunicates, 453
Turbellaria, 386–387
Turbinates, *622*
Turgor pressure, 75–77, 321
Turkeys, 178, 518, 738–739
Turtles, *456,* 502–*504*
Tusks, in walruses, 531
Twigs, 325–326; grafting and, 336–337
Twins, *159–160,* 167
Twort, F. W., 216
Tympanic membrane, 478, 504, 622
Tympanum, of grasshopper, 429
Typhoid, 228, 240
Typhus fever, 235
Tyrosine, 168

Umbilical cord, 655, 656
Ungulates, 531–532
Unicellular organisms, 65, *66*
Univalve mollusks, 402
University of Lille, 222
Uracil, 51, 96, 98
Urea, 569, 577 582, 594
Uredospores, 271
Ureters, of frog, 479, 482; human, 595, *596*
Urethra, 596; male human, 648, 649
Uric acid, 516–517, 594
Urine, of frog, 482; human, 569, 596
Uropod, of crayfish, 413
Urothrombin, 581
Uterus, embryo in, 652–655, *654;* in flukes, 388; of frog, 483; human, 650–655
Uvula, 572

Vaccination, 2, 5; smallpox, 213
Vaccine, anthrax, 245–246; definition, 249; rabies, 247; Sabin oral, 8, 10; Salk, 7–8; smallpox, *245*–246
Vacuolar membrane, 57, 60, 62; pigments, 62–63
Vacuoles, 57, 62–63, 79; in ameba, 255–256; contractile, 76, 255–256, 258; of paramecium, 257–258
Vagina, 650, 655
Vagus nerve, 619
Valves, a-v, 588–589, 590; (shells), 401; s-l, 589, 590
Vampires, 525
Van Helmont, Jean, 19, 25
Van Leeuwenhoek, Anton, 13
Vane, of feather, 509

Variations, 30–31, 52; among bees, 436–437; animal breeding and, 178–180; of birds, 507; and evolution, 187; floral, 352, 354; genetic, 52, 112, 135–136, 137–139, 190, 231, 648; industrial melanism and, 192; in mammals, 522, 533; migration and, 190–191; mutations and, 188–189, 190, 191; plant, 171, 176–178; recombination and, 189; and speciation, 194–195; as Linnaean grouping, 204; *see also* Adaptations
Vas deferens, 648
Vasa efferentia, of frog, 482
Vascular bundles, leaf, 341; stem, 333–334
Vasopressin, 642
Vegetables, 566
Vegetative, organs, of flowering plants, 306–307; propagation, 147, 173; reproduction, *108;* by roots, 319
Veins, of fish, 466; of frog, *481*; hepatic, 593; human, 590, 591–596, 602, 603; leaf, 341
Venae cavae, of frog, 481; inferior and superior, 589, 591, 593, 596
Venation, leaf, 341
Venom, 494, 497–498, 499–500, 501
Ventilation, 608–609
Ventral, aorta, of fish, 466; blood vessel, of earthworm, 395; nerve cord, of earthworm, 396; nervous system, 410, 412; siphon, of mollusks, 400; surface, 386
Ventricles, 588, 591; of bird, 517; of brain, 615; of fish, 466; of frog, 480
Venules, 591
Venus's-flytrap, 345, *346*
Vergil, 19
Vermiform appendix, 576
Vertebrae, 453, 560
Vertebrates, brain, 535–*536;* characteristics, 452, 453, 454–455; classification, 374–375; shape, 386
Vesalius, Andreas, 2
Vessels, plant, 310; stem, 332
Vestigial organs, 182, *184*
Veterans Administration Hospital, 219
Viability, seed, 366
Vibration; of eardrum, 623
Villi, chorionic, 654–655; in small intestine, 579
Vinegar, bacteria and, 232
Vipers, 498–499
Virulence, of viruses, 215
Viruses, 212–220, *214;* polio, 6, 8; rabies, 246–247
Visceral hump, of mollusks, 400, 403
Visual purple, 627
Vitamin deficiency, alcohol and, 631
Vitamins, 270, 556–557, 565, 569–571, (Table) 570, 581
Vitreous humor, 625
Viviparous, 497
Vocal, cords, 601; sacs, of frog, 479
Volcanoes, 666
Volvox, 385
Vomerine teeth, 478, 479
Von Behring, Emil, 248
Von Tschermak, 132
Vultures, 513

Wak-Wak tree, *20*
Waksman, Dr. Selman, 251
Walking stick, *430*
Wall, cell, 57, 63, *65,* 224–225
Walruses, 531
Warblers, 512, 519, 690
Wasps, 439
Wastes, 57; nitrogenous, 582, 594, 630; undigested; *see* Elimination
Water, absorption in colon, 579; conservation of, 718–720; cycle, *664*–665; dog, *474;* diffusion into cell, 75–77; and environment, 675–676; erosion, 715–718; evaporation of, 565, 597, 665, 676–677; fleas, 418; as food, 565–566; and living organisms, 43; molds, 268, *269;* molecular structure, 38–39; molecules split in photosynthesis, 85–88; pollution, *733*, 734; power projects, 720; table, 665, 719
Water-borne infections, 240–241
Water-vascular system, 404–405
Watersheds, 719–720
Watson, James D., 49, 50
Watusi, 159
Wax, 46, 443
Weasel family, 531
Weather, forests and, 728, 731
Web, spider, 419
Web membrane, 478
Webbed feet, of birds, 512; frog, *476*, 478; in water-living carnivores, 531
Weevils, 440
Weismann, August, 131
Weller, Dr. Thomas H., 6
Whales, 528, 529, 708
Wheat, 569; breeding and, 171, 178; rust, 271, *272*
Whipworm, 390
White corpuscles, 560, 582, 583, 591, 594; matter, 614–615, 616, 617; and pneumnoia, 144
Whooping crane, 735–736
Wickman, Dr., 6, 9
Wiggler, 442
Wildlife, conservation of, 731–739
Wilting, 76, 350
Wind erosion, 717–718
Wind-pollinated plants, 357
Windbreaks, *717*
Windpipe of frog, 480; human, 600–601
Winds, 677; and seed dispersal, 363
Wings, of bee, 435–436; bird, 509, *510*–511; of butterfly or moth, 433; of grasshopper, 426, 427; of housefly, 441; of Hymenoptera, 435; of Isoptera, 439–440
Withdrawal symptoms, 633, *635*
Wolverine, 531
Wolves, 530
Wood, stem types, 329–330; tissues in, 332; xylem as, 316
Woodchuck, 525
Woodcock, 512
Woodpeckers, 53; ivory-billed, 735
Woody, plants, 310; stems, 325–333, (Table) 333
Worms, 385–396; parasitic, 238
Wound infection, 241
Wounds, healing, 583–586

X chromosomes, *136*–137, 138–139, 140–141, 149
X rays, and insect control; 447, 448; and mutations, 148, 149, 151
Xanthophylls, 61; in leaves, 345–346
Xerophytes, *675*, 676, 704
Xylem, 308; fibers, 332; parenchyma, 332; root, 316, 317

Y chromosomes, 136–137, 138–139, 140–141, 149
Yeasts, 24, 269–*270;* and fermentation, 223, 270; reproduction, 108; vinegar and, 233; vitamin B_2 and, 270
Yolk sac, of fish, 469; human, 654
Yolks, of birds, 518

Zoospores, of *Oedogonium*, 283–284; of *Ulothrix*, 283
Zones, climatic, 700, *701*–707; ocean, *707*–708
Zygotes, 109, 110, 112; of algae, 278; of bread mold, 267; of fern, 300; formation, 648; human, 652–653; in hydra, 380; in medusa, 381; of *Oedogonium*, 284; of plant, 358; *Spirogyra*, 282; of *Ulothrix*, 283, 284–286

DATE DUE SLIP

APR 22 RETURN
Returned OCT 19'77
EDUC NO 16 '77
Returned NOV 17'77
DUE Educ SEP 15'78
RETURNED JUN 26'78
DUE EDUC JAN 29 1992
RETURNED SEP 28'78
1992 DEC 15 RETURN
DUE Educ OCT 15'78
OCT 12 RETURN
DUE Educ DEC 1'78
RETURNED NOV 24'78
EDUC FE [illegible]
RETURN JAN 30 '80
[illegible] FEB 17'85
FEB 17 RETURN
[illegible] 01'88

DEC 01 RETURN
DUE EDUC MAR 06 '87
DUE EDUC MAR 13 '87 R
DUE EDUC MAR 20'87 R
MAR 18 RETURN

QH 307 M818 1965 C-2
OTTO JAMES H JAMES HOWARD
MODERN BIOLOGY

NL 39128058 CURR HIST

000000686402

QH 307 M818 1965 C. 2
Otto, James Howard.
Modern biology.

0028370B CURR
U OF A.

2391411

1479005